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COMPREHENSIVE STUDIES OF SOLID WASTE MANAGEMENT

C. G. Golueke, et al

California University
Berkeley, California

1970

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COMPREHENSIVE STUDIES OF SOLID WASTE MANAGEMENT

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COMPREHENSIVE STUDIES OF SOLID WASTE MANAGEMENT

First and Second Annual Reports

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to the University of California
were prepared by C. G. GOLUEKE and P. H. McGAUHEY
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I

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II

FOREWORD

At the time of passage of the Solid Waste Disposal Act (PL 89-272) in 1965, few, if any, studies of a truly comprehensive nature had been undertaken to develop solutions to problems in all aspects of solid waste management. Although earlier research studies have made invaluable contributions to knowledge in the field, they tended to focus primarily upon discrete facets of the total solid waste problem.

The present report represents the first major effort to examine the solid waste problem from the standpoint of systems analysis. An overall solid waste generation and evaluation model was developed, demonstrating interrelationships between land use, technology, economics, population, and other system elements. Practical implications were drawn from this model, as they relate to planning, public health, and application of technology.

A further example of the systems approach to solid waste management is given in the final report of a Bureau of Solid Waste Management demonstration project, *A Systems Study of Solid Waste Management in the Fresno Area* (Public Health Service Publication No. 1959).

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

COMPREHENSIVE STUDIES OF SOLID WASTE MANAGEMENT

First Annual Report

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PREFACE

NATURE AND SCOPE OF REPORT

The report herein presented is of the nature of a progress report covering the first year of a comprehensive study of solid wastes management made possible by a grant (SW-00003-01) to The Regents of the University of California by the Public Health Service.

The research plan on which the grant was based called for an initial organizational and general data-collecting phase, covering a major part of the first year, followed by a second phase of definitive research on such aspects as operations research, planning, economics, public health, and technology of wastes management systems. The first phase having been successfully completed, the report on this aspect is essentially a final report intended to acquaint the reader with the underlying concepts of the solid wastes problem and with the details of the multidisciplined research program set up to attack the problem. On the definitive research phase of the program, progress and preliminary findings of a number of coordinated research teams are presented in detail.

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Characteristics and Amounts of Solid Wastes in Santa Clara County — J. Becker

Operations Research — H. Stern and Professor C. R. Glassey

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Incineration — H. Wasmer and Professor P. B. Stewart

Anaerobic Digestion — S. A. Klein and D. B. Chan

Wet Oxidation — J. Bicho and Dr. D. L. Brink

Biological Fractionation of Solid Wastes — S. Cherney, R. Rosenbluth, and Professor C. R. Wilke

Salvage — J. Becker

TABLE OF CONTENTS

Page

PART I
BACKGROUND

Chapter

I. INTRODUCTION 1
   Need for Study 1
      Urbanization 2
      Economic Considerations 3
      Technology 3
      Public Health 4
      Education 4
      Conclusion 5
   Nature and Rationale of Study 5
   Objectives of Study 10
   Organization for Study 10
   Plan of Research 11

PART II
PHASE I OF THE INVESTIGATION

II. DATA COLLECTION AND EVALUATION 15
   Literature Survey and Information Retrieval 15
      Papers 15
      Reports 15
      Journals 16
   Personal Interviews 16

TABLE OF CONTENTS (continued)

Chapter Page

Characteristics and Amounts of Solid Wastes 17

Introduction 17

Need for Refuse Analysis Studies 18

General Estimates of Refuse Composition 18

Specific Estimates of Refuse Composition 19

Waste Generation in Santa Clara County 19

Domestic Wastes 20

Industrial Wastes 21

Agricultural Wastes 21

Change in the Composition of Berkeley Wastes 30

Introduction 30

Equipment and Procedure 31

Results 32

Discussion 36

Definition and Coordination of Research Areas 39

PART III
PHASE II. DEFINITIVE RESEARCH

III. OPERATIONS RESEARCH 41

Introduction 41

Waste Generation and Evaluation Model 41

Waste Collection-Treatment-Disposal Model 44

General Description 44

Mathematical Formulation 45

Waste Generation Input and Management System Inputs 48

Management System Inputs 48

Waste Generation Model 48

Regional Economic Model (Productive Sector) 50

Waste Generator (Consumption Sector) 51

Spatial Distribution of Waste 52

TABLE OF CONTENTS (continued)

Chapter Page

Future Extensions and Tasks 54

IV. PLANNING AND ECONOMICS 55

Introduction 55

Approach and Methodology 55

Model Formation 56

Development of Pertinent Data on Quantity and Types of Solid Wastes 57

Solid Waste Generation and Land-Use Planning 57

Incorporation of Technical Changes in Transportation and Disposal of Solid Wastes 58

Implications of Present and Future Methods of Disposal on Private and Public Expenditure 58

Santa Clara County Study 59

Introduction 59

Location of Disposal Sites and Definition of Disposal Service Areas 59

Land-Use and Employment Data 60

Solid Waste Data 67

Composition of Solid Wastes 67

Regression Study 67

Data Collection Plans 73

V. PUBLIC HEALTH 75

Introduction 75

Objectives of Public Health Research 75

Relationship of Wastes Management to Health 76

Relation of Wastes Components to Health 79

Agricultural Wastes 80

Industrial Wastes 80

Methods of Disposal 81

Incineration 81

Sanitary Landfill 86

TABLE OF CONTENTS (continued)

Chapter Page

Composting 89

Occupational and Health Hazards 91

VI. TECHNOLOGY OF SOLID WASTES MANAGEMENT 93

Introduction 93

Incineration 93

Concept and Rationale 94

Objectives 94

Refuse Pretreatment Studies 95

Pyrolysis Studies 96

Composting 100

Concept and Rationale 101

Objectives 101

West German Studies 102

Landfill 104

Salvage 105

Concept and Rationale 105

Objectives 106

The Investigation 106

Metals 106

Paper 108

Glass 111

Rubber 113

Plastics 114

Rags 116

Summary and Conclusions 117

VII. ANAEROBIC DIGESTION WITH SEWAGE SLUDGE 118

Introduction 118

Concepts and Rationale 119

Objectives 119

TABLE OF CONTENTS (continued)

Chapter | Page

The Investigation 120
Development of Equipment and Procedures 120
Preparation of Raw Materials 120
Sewage Sludge 120
Digester Units and Ancillary Equipment 120
Gas Lines and Collectors 123
Analyses 126
Total and Volatile Solids 126
Volatile Acids 126
Gas Analysis 126
Alkalinity 126
Experimental Procedures and Results 126
Procedure — Specific 128
Results 129
Volatile Acids 129
Gas Production 129
Gas Composition 133
Alkalinity 133
Hydrogen Ion Concentration (pH) 136
Reduction in Volatile Solids 136
Discussion and Conclusions 136
Future Work 140

VIII. WET OXIDATION OF ORGANIC WASTES 142
Introduction 142
Description of the Process 142
Historical 144
Pilot- and Large-Scale Applications 145
Recent Research 151
Application to Solid Wastes 152

TABLE OF CONTENTS (continued)

Chapter Page

Objectives of Study 154

The Investigation 154

Program and Methodology 155

Phase 1: Determination of Basic Reaction Relationships 155

Phase 2: Oxidation of Organic Solid Waste Materials 157

Phase 3: Process Design 159

Progress in Equipment Modification 159

Discussion 159

Future Work 160

IX. BIOLOGICAL FRACTIONATION OF ORGANIC WASTES 161

Introduction 161

Waste Treatment Organisms 161

Rumen Bacteria 161

Clostridia and Related Forms 161

Fungi Imperfecti 162

Application to Solid Wastes 163

Objectives of Study 164

The Investigation 164

Summary 165

PART IV

X. SUMMARY 167

Introduction 167

Nature of Research Program 168

Research Activities and Findings 169

Phase I 169

Phase II 170

Operations Research 170

TABLE OF CONTENTS (continued)

Chapter Page

Planning and Economics 170

Public Health 171

Technology 172

General Summary of Progress 174

REFERENCES 175

APPENDICES

A. Application of the Evaluation Model to Special Cases 185

B. Design of Transfer Station Characteristics 186

C. Comparable Data on Solid Waste and Related Economic Variables 192

D. Questionnaires to Refuse Collectors and Disposal Site Operators for Analysis of Refuse Collection and Disposal . . . 194

E. Codification of Data 199

LIST OF TABLES

Table	Title	Page
1.	Summary of Participants in the Program	13
2.	Estimate of Gross Refuse Generation in Santa Clara County (1967) . .	20
3.	Estimate of Components of Domestic Refuse in Santa Clara County (1967)	20
4.	Principal Expected Wastes from Manufacturing and/or Processing Industries, Santa Clara County, California	22
5.	Classification of Manufacturing Firms in Santa Clara County, California, by Numbers and Employee Groups	23
6.	Sources and Types of Industrial Wastes, Santa Clara County	24
7.	Distribution of Dairy Manure Generation in Santa Clara County . . .	26
8.	Pountry Manure Generation in Santa Clara County	28
9.	Quantities of Prunings by Crops in Santa Clara County	29
10.	Weight of the Individual Loads of Refuse and the Percentage of Total Refuse Per Route That Was Segregated	33
11.	Type of Account Receiving Refuse Service	33
12.	Composition of Berkeley Refuse in Terms of Weight	34
13.	Composition of Berkeley Refuse in Terms of Percentages	34
14.	Comparison of the Composition of Refuse in 1967 With That in 1952 in Terms of Weight	35
15.	Changes in Composition of Refuse Over 15-Year Period	35
16.	Information Flow for Regional Waste Generation and Evaluation Model	43
17.	Solid Waste Disposal Sites in Santa Clara County	61
18.	Disposal Service Areas and Corresponding Disposal Sites in Santa Clara County.	63
19.	Definition of Disposal Service Areas by Planning Areas and Census Tracts in Santa Clara County	64
20.	Land Use by Planning Areas and Portions of Planning Areas for Selected Land-Use Categories, 1962, Santa Clara County	65
21.	Land Use by Disposal Service Areas for Selected Land Use Categories, 1962, Santa Clara County	66
22.	Employment by Planning Areas, July 1964, Santa Clara County	68

LIST OF TABLES (continued)

Table Title Page

23. Employment by Disposal Service Areas, 1964, Santa Clara County 69
24. Summary of Information from Questionnaire 70
25. Disposal Site Operating Costs — Imputed and Reported 71
26. Estimates of Solid Wastes by Broad Categories in Santa Clara County, 1965 72
27. Data Used for Regression Analysis, Santa Clara County 74
28. Santa Clara County Waste Generation, Summary of Linear Regression Results 74
29. Possible Health Problems in Solid Wastes Management 77
30. Air Pollutant Emissions from Solid Waste Disposal 83
31. Tons of Contaminants Introduced into Los Angeles County Atmosphere, 1962 84
32. Summary of Air Pollutant Emissions in St. Louis Area Study, 1963 85
33. Concentration of Leachate from Simulated Landfills Contained in Concrete Cylinders 87
34. Estimation of Pollution from Refuse Beds of Various Depths During Percolation of the Equivalent of 45 in. of Rainfall 87
35. Composition and Analysis of a Composite Municipal Refuse (1966) . . 98
36. Chemical Analysis of Raw Refuse 99
37. Chemical Analysis After Drying and Separation 99
38. Summary of the Material Balance Concerned with the Pyrolysis of Municipal Refuse 100
39. German Composting Plants 103
40. Prices Paid FOB Stockton for Papermaking Stock 110
41. Daily Feed Composition 128
42. Nitrogen and Oxygen Content of Digester Gas 133
43. Volatile Solids Reduction 139
44. Average Chemical and Physical Properties of Spent Neutracel Liquor Before and After Oxidation 146
45. Average Performance of Pilot-Scale Sewage Sludge Wet Oxidation Studies 148
46. Average Chemical Characteristics of Process Effluent from Pilot-Scale Sewage Liquor Sludge Wet Oxidation Studies 148

LIST OF TABLES (continued)

Table | Title | Page

47. Summary of Typical Operating Conditions for Existing Sewage Sludge Wet Oxidation Plants 148

48. Unit Costs for the West-Southwest Wet Oxidation Plant of the Metropolitan Sanitary District of Chicago, Illinois 150

49. Unit Costs for the Wet Oxidation Plant at Wheeling, West Virginia . 150

50. Unit Costs for the Blind Brook Wet Oxidation Plant at Rye, New York 151

51. Potential Value and Volume of Organic Acid Production from Spent Pulping Liquors 153

52. Distribution of Fermentation Products by Pure and by Mixed Cultures 162

LIST OF FIGURES

Figure	Title	Page
1.	Types of Waste Disposal Systems	8
2.	Organization of Study	12
3.	Planning Areas and Distribution Dairies in Santa Clara County	27
4.	Setup for Segregating Refuse at the Berkeley Waste Disposal Site	32
5.	Weighing Segregated Refuse Items	32
6.	Typical Glass Waste Segregated in the Berkeley Study	36
7.	Typical Plastics Segregated from Domestic Refuse	37
8.	Tin Cans Segregated from Domestic Refuse	37
9.	Regional Waste Generation and Evaluation Model	39
10.	Mathematical Model of Waste Generation	42
11.	Waste Flow Network	45
12.	Management System Inputs and Waste Generation Model	49
13.	Solid Waste Disposal Sites and Service Areas, Santa Clara County	62
14.	Schematic Description of Overlapping Disposal Sites	63
15.	Material Flow in Refuse Pyrolysis	97
16.	Experimental Digester	121
17.	Stirring Device Layout	122
18.	Incubator Containing Four Digesters	123
19.	Liquid Displacement Gas Collector	124
20.	Inverted Tube Gas Collector	125
21.	General View of Gas Collection Apparatus	127
22.	Effect of Green Garbage on Volatile Acids Production of Digesters	130
23.	Effect of Green Garbage Loading on Gas Production	131
24.	Effect of Green Garbage on Digester Performance	132
25.	Effect of Green Garbage Loading on Methane Concentration of Digester Gas	134

LIST OF FIGURES (continued)

Figure	Title	Page
26.	Effect of Green Garbage Loading on Carbon Dioxide Content of Digester	135
27.	Effect of Green Garbage on Alkalinity of Digesters	137
28.	Effect of Green Garbage Loading on pH of Digesters	138
29.	Schematic Diagram of Continuous Wet Oxidation Process Developed by Zimmermann	143
30.	Schematic Diagram of the Proposed Batch Wet Oxidation Process . .	156
31.	Schematic Diagram of Air System Designed for Wet Oxidation Process	158
32.	Direct Transfer Station and Disposal Station	187
33.	Indirect Transfer Station and Disposal Station	187

PART I
BACKGROUND

I. INTRODUCTION

NEED FOR STUDY

The need for comprehensive studies of solid wastes management, to which the investigation herein reported is directed, derives from a long history of inadequate public attention to problems of resource management and environmental control, with the result that when solid wastes problems reached critical proportions in the 1960's, jurisdictional arrangements, economic concepts, social attitudes, and technology were all found ill-suited to their resolution.

The origins of these four interrelated areas of inadequacy are perhaps to be found in the abundance of natural resources our ancestors found on the American continent and in the wasteful manner in which they exploited these resources in establishing an agricultural and, later, an industrial economy. While it may be argued that to a considerable degree destruction of some resource values was an inescapable aspect of occupying a wilderness by agrarian people, it did establish a spendthrift attitude which persists as a part of the cultural heritage of Americans and is reflected today both in the amount and the nature of solid wastes as well as in public attitudes toward unwanted residues.

Concerning the attitude of citizens and public officials toward the residues of resource utilization it might be said that any material becomes a "waste" when its owner or producer no longer considers it of sufficient value to retain. Thus no question of the intrinsic value of the material either as a resource or as an object of further utility is involved in the reaction. Once it is no longer valued by the owner, any suggestion that he should further invest money in it, for the sake of disposal or any other financially unrewarding goal, is likely to be considered absurd, however inclined he may be to deplore polluted water, smog, unsightly debris, rodents, or other conditions which result from his loss of interest in ownership.

Reflecting the attitude of the citizen, engineers and officials responsible for wastes management in the community have tended to apologize for the fact that their systems cost anything at all, often retreating from expedient to expedient on the basis of minimum immediate expenditure of money. Thus there is at work in the community little which might make for a public realization that wastes management is worth whatever it costs within the framework of sound engineering and the health and social goals of people. Correlated with this attitude has been a tendency of some municipal officials to consider a policy of no-spending-at-all as the ideal goal of municipal government or, more recently, to direct spending to more popular social objectives or to monumental works having greater cultural appeal than the refuse dump.

The result of all facets of the public attitude has been a very low estimate of the cost the public can "afford" to pay for waste disposal and a hesitancy to dedicate land and other resource values to such an end. This does not mean, however, that little money goes into our attempts at solid wastes management. The Public Health Service has estimated that some three billion dollars is spent by the public each year in collecting, transporting, and disposing of solid wastes. When it is noted that this is second only to the annual investment in public education and that it is yet hopelessly inadequate to the task of solid wastes management, citizen and public official alike may justifiably wonder if there is not some better approach to the problem.

From such a question one senses a need for some sort of comprehensive study of the whole matter of solid wastes management. To get at the nature of such a need, however, it is necessary to look at aspects other than traditional economic attitudes of the public and our heritage of wastefulness. One of the most significant factors is the nature of a modern urban community.

Urbanization

The jurisdictional, or political, subdivisions of a modern community were originally founded on a spectrum of valid social and political needs which ranged from the distance one could travel by horseback in one day to the need of settlers for stores, services, or protection from Indians. Resources management, and above all management of the residues of resource use, were simply not problems which confronted pioneer America to a degree sufficient to influence the nature of his settlements. As settlements grew into cities, however, the problem of waste disposal grew likewise, but no new dimension appeared at once. Cities throughout the world, wherever men have achieved a high degree of consciousness of health and aesthetics, have traditionally dealt with wastes by transporting them beyond their own immediate confines and discarding them in the least expensive way the public might tolerate, advancing from open dump, to sanitary landfill or incinerator, as local necessity compelled. No serious problems need arise from this practice as long as cities or jurisdictions are separated by space occupied only sparsely by human beings. And such was the case for many decades.

The rapid spread out of cities, popularly known as the "urban-sprawl," which followed World War II is now widely recognized as having revolutionized our concepts of urban life. Less well understood, however, is its effect in expanding the problem of solid wastes management to area-wide proportions beyond the resolving power of any one of the myriad jurisdictions that make up the overall modern community. Even in situations where one city is located at some distance from another, particularly where explosive increase in population has had a maximum impact, urbanization has progressed beyond the limits of cities and their satellite suburbs to become a characteristic of rural areas as well. With high land values and heavy investment in fixed installations dedicated to such specialty enterprises as dairies, poultry and egg production, and animal feeding, this rural sector of the community now surrounds the urban-industrial-suburban sector as a shell which has lost the elasticity traditionally associated with rural areas. Moreover, it exists in sufficient depth to have a profound effect on both its own and the city's problem of wastes management.

The high-investment rural sector of the community constrains the city's freedom to dispose of wastes by the traditional export method. In some cases, such as California, there are desert areas beyond the rural shell but the long haul distances involved are currently judged to be prohibitively expensive. In other sections of the United States there is simply no area beyond the limits of the city where high-value agriculture gives way to marginal or worthless land. The alternative to export is, of course, disposing of solid wastes within the city limits. In most cases this is an unsatisfactory alternative. Land area is at a premium and land use planning generally not sufficiently advanced to include refuse disposal objectives. Moreover, the constraint is often three-dimensional as air pollution considerations limit the freedom to burn combustible wastes. Within the city itself transportation needs and efforts to revitalize the urban environment in other ways contribute a new problem of solid wastes in the form of demolition debris, thus compounding an already complex internal problem of managing municipal and industrial residues.

Just as the city is confined by the surrounding rural sector, it in turn exerts pressure against the freedom of that sector to manage its wastes by traditionally cheap methods. Air pollution control limits the burning of orchard trimmings and other agricultural residues, water pollution considerations bring to an end the practice of placing animal fattening pens astride streams and pushing manure into the water; and the fly-producing potential of manures triggers nuisance-abatement actions by burgeoning suburbs. Collection of manures is expensive and, with agriculture's current disinterest in manures, the collected material is as undisposable as the city's refuse. The city's response to the urban problem is often an extension of its limits to overwhelm agricultural enterprise with ruinous taxes, thus leading to more subdivisions and a loss of agriculture which is in no way beneficial to the economy.

In many communities the situation is made more complex than that of an urban-suburban core impinged on a rural sector by the fact that the urban core itself consists of several contiguous incorporated cities, each confined by its own geographical and jurisdictional limits. For example, in the San Francisco Bay area some 83 separate but impinged jurisdictions and agencies seek to deposit their solid wastes in each other's back yard at 77 locations.

Obviously there is need for a study of the ways in which an overall urban community can organize itself to deal with all types of solid wastes generated in its several sectors.

Economic Considerations

Implicit in public attitudes toward waste materials and in the unintegrated situation arising from urbanization is the problem of economics. Concern in this sphere, however, transcends both the concept of what the public can "afford" to pay and the question of why the expenditure of three billion dollars each year has not staved off a crisis in solid wastes management. The truth is that our national economy depends to a significant degree upon the generation of wastes. While there is reason to presume that a departure from our traditional wastefulness of resources might reduce the problem of solid wastes management by reducing the volume of wastes to be managed, there is no clear answer concerning its effect on the American standard of living. From the obvious premise that in the long run we shall have to conserve resources, it may be concluded that also in the long run the volume of wastes will be reduced. However, the problem of wastes management is immediate and no immediate change from an economy based on consumption of goods (production of wastes) is in view. Therefore there is a need for studying ways in which wastes themselves may be salvaged, reworked, and recycled back into the resources that are being exploited for economic good.

Technology

Closely related to economic considerations are the technological aspects of wastes management. Here two levels of concern are evident: the technology that produces consumer goods from natural resources, and the technology of disposal of the residues of such production and of goods themselves when they are discarded by the consumer. With the exception of the new detergent introduced in 1965, and current efforts in the field of pesticide formulation, there is essentially no instance in which one of the objectives of the product designer has been its ultimate disposability. In fact "disposability" has been interpreted only in terms of convenience to the user; a convenience characterized by single usage, with increased consumption and consequent magnification of the volume of solid wastes generated. Similarly, new types of materials are developed for all manner of objectives ranging from intrinsic properties to appeal to the user. Markedly absent, however, is the objective of the ultimate disposal. Thus a synthetic plastic, for example, may be far better than the product of nature for commercial and industrial products — for toothbrush handles, ball point pens, and breakable toys — and yet they increase rather than decrease the problem of ultimate disposal.

At the more common level of technology — that of solid waste disposal — numerous deficiencies exist. To begin with, attention has largely been directed to the disposal of municipal refuse, i.e., the refuse collected from households and commercial establishments within an urban community. Thus technology of disposal has not developed in relation to the entire solid wastes problem of the community. Agricultural residues, animal manures, demolition debris, industrial wastes, sewage sludge, old automobiles and junk, and food processing wastes have each been viewed as a separate problem of concern to some segment of the community rather than to the public as a whole. In this circumstance there is little knowledge of the logistic, economic, or technological problems of disposing of the collective refuse of an urban-industrial-agricultural community.

Attention to the technology of disposal of the municipal fraction of solid wastes has, as previously noted, been handicapped by public attitudes toward wastes and overwhelmed by the advance of urbanization. Specifically, incineration is confronted with new constraints arising from air pollution problems in many areas as well as with a greater variety of materials to be burned; landfill operations are beset by rising land costs, shortage of available landfill sites, and increasingly restrictive environmental objectives of society; and composting, never quite commercially successful in the United States where applied to municipal refuse, is further delayed by the rise of plastics and the unknown factors in community-wide wastes management. Essentially no experience exists in the technology of reprocessing wastes to produce raw materials for industrial use.

Thus it may be said that there is need for study of ways to: 1) adapt existing technology to area-wide waste disposal; 2) develop new technology for reprocessing and reestablishing resource values of wastes; and 3) relate the technology of production to the objective of the ultimate fate of the product.

Public Health

Inasmuch as the least expensive method of disposing of unwanted materials is to throw them into an open dump, public health considerations long ago became a factor in solid wastes management. Primarily the problem is one of identifying and controlling the conditions under which flies, mosquitoes, rodents, and other vectors of disease are sustained by refuse in the household, the collection system, or the disposal procedure. Urbanization and the community-wide nature of solid wastes problems have, of course, served to enlarge the scale of this aspect of public health. Changing industrial technology, with its creation of new and exotic materials which find their way into waste, may or may not add a new dimension to public health concern. Little is known of the environmental hazards that might result from routing such materials through waste disposal processes. At the same time, the goals of environmental control have transcended the objectives of prevention of nuisance and infection of people with disease. "Quality of the environment" and "quality of life itself" are today commonly expressed objectives of environmental management which in a broad sense involve public health concern. Consequently there is need for a restudy of the relationship of solid wastes management methods to man's health and welfare, and for an entirely new look at the components of refuse and their fate in waste disposal practices. It may well be that no new public health concern accompanies the growing problem of solid wastes management but the truth in this matter is presently not known.

Education

One of the major facets of the current crisis in solid wastes management is the historic and contemporary ignorance by both the public and its officials of the nature of the problem. Brief attention has been called to the basis of this ignorance in a discussion of public attitudes. Other contributing factors are the complexity of problems in a modern community on which people ought to be informed, the absence of the subject from the context of formal educational programs, and the near absolute misinformation in the public press.

In the absence of educational contact with the solid wastes problem, urban land-use planners have almost universally ignored solid wastes disposal as one of the necessary considerations. Similarly the broad humanistic program of the administrator, the economist, and the political scientist has little room for such mundane concerns as refuse. Engineers have been traditionally oriented to water pollution problems, and even the public health official receives but a minimal orientation to solid wastes problems. While it may not be realistically contended that the professional education of such people should include a course in refuse management, the truth remains that those who (as public officials) are to be confronted with the solid wastes problem face such confrontation with little more knowledge than that of any other citizen.

The citizen gets his information largely from the popular press. Within the past two years there have appeared in several magazines extremely well-written analyses of various pollution problems. Unfortunately these serve largely to make the citizen aware that a problem exists, and that it is going to cost (presumably the federal government) a vast sum to correct it. Details of the problem reach the citizen through the local newspaper concerned with the local problem. It is at this point that information seems to break down. Officials and citizens alike persist in such mistaken assumptions as that incineration is an alternative to landfill, that land simply cannot be found for solid wastes disposal, and that by refusing to accept feasible solutions to the solid wastes problem "somebody" will find a way to make wastes disappear, albeit not into the air. In perusing newspaper articles over an 18-month period in 1966-67 the authors of this report found no instance where the public was told, for example, that some 50 percent of solid wastes must be disposed of upon land regardless of how wastes are managed short of recycling to the resource.

These and other limitations of public information, however understandable, indicate that a major need exists for education in the area of solid wastes management at two major levels:

1. Education of planners, public administrators, engineers, economists, political scientists, public health officials, and others who are confronted with the problem of solid wastes management in the course of their professional service to the public.

2. Education of the public itself concerning the solid wastes problem and the role of the public in its solution.

Conclusion

From the foregoing summary of the origin and nature of several aspects of the problem of solid wastes management it is concluded that:

1. There is a need for a comprehensive study of solid wastes management on an area-wide scale.

2. The needed study should involve the coordinated effort of investigators with a wide variety of backgrounds.

NATURE AND RATIONALE OF STUDY

The study herein reported is of the nature of a research program designed to achieve a maximum of education of professional personnel through participation of graduate students and faculty from the wide spectrum of disciplines described in a subsequent section (Organization For Study). It is derived from the needs for study outlined in the preceding section and is based upon a number of general and specific concepts.

First it is recognized that all wastes are for the foreseeable future destined to remain somewhere in the earth or its gaseous envelope. Within such a system the ocean is the only ultimate sink, although for practical purposes of solid wastes management the dry land may also be considered a sink. The atmosphere and flowing streams represent transport systems and cannot be made to function as sinks. They have a limited capacity to accept wastes however cheaply they may deliver their loads to the sea or land. Thus the general problem of research is to find the optimum way to sequester wastes in the earth without interfering with man's freedom to use the earth's resources as he sees fit.

A second general concept is that "wastes" are more properly defined as residues of resource use which result from the application of current technology under present concepts of economics and social objectives. Thus both the amount and nature of solid residues are subject to change with either time or the objectives and concepts of people, or both. If such residues are conceived as "resources for which we have not yet found a use," technological research might be expected to take the direction of methods of stockpiling residues until such time as they are needed. Such research might relate to methods for segregating, transporting, preserving, and sequestering valuable material. If conceived as resources which should be utilized immediately, research would be concerned with how to make products more reusable and with the technology of segregating and recycling them as well as of minimizing their volume and, hence, the cost of their reclamation. If conceived as forever worthless material, then research should continue along the lines of how to collect, transport, process, and sequester whatever uncontrolled volume and variety occurs without inhibiting man's freedom of movement, unduly contaminating his environment, or seriously interfering with his use of land, water, and air resources.

For the immediate future it is expected that the "resources" concept of residues is less likely to prevail than the "wastes" concept for the reason that there is a big backlog of immediately urgent problems begging solution; and that the long-range effects of the results of research will be to make it possible to recycle and reclaim resource residues.

A third general concept is that a program of research can simultaneously achieve many of the objectives of the needed educational program while contributing to the solving of jurisdictional, planning, economic, and technological problems of solid wastes management.

Within the framework of the foregoing general rationale the research program involves a number of more specific concepts of which the following are the most important.

1. The problem of solid wastes management must be attacked on a community-wide basis and must take into consideration residues characteristic of all sectors of the community — urban, industrial, and agricultural. This involves studies of both the jurisdictional system necessary to implement such a concept and the physical system necessary to handle wastes pursuant to any combination of disposal methods. Thus a need exists for the application of the techniques of systems analysis and operations research.

2. As a prelude to technological solutions, a preliminary dimensioning of the community-wide problem of wastes management should include consideration of the meteorological and ecological effects of feasible methods, as well as of the economics of reuse of land which serves as the sink for solid wastes either within or outside the confines of the community.

3. It is not necessary to accept the idea that the volume of wastes and the scarcity of sinks requires that disposal be the principal objective of a sanitary landfill. Conversely, land use planning cannot ignore the necessity for residues to be returned to the earth. Thus the role of refuse disposal in land use planning needs to be studied and widely recognized.

4. Long-distance hauling of refuse has generally been considered uneconomical. However, no analysis of the technical and economic potential of the U.S. transport system underlies this assumption. It is conceivable that the facilities of rapid transit systems, railways, highways, and waterways could be organized to transport solid wastes to remote areas where in properly managed landfills it would be stored until some later generation finds a way to utilize its resource potential. Here again a systems and economic analysis is in order.

5. The sewerage system of a modern community is designed to transport peak-hour loadings of quite dilute wastes and to apply treatment processes

likewise based on the removal or stabilization of low concentrations of solids. Most efficient use of a transport system, however, requires that it be loaded to capacity at all times. It is therefore conceivable that during the night hours of low flow, trunk sewers could be flushed with return effluent, possibly pumped from the treatment plant at high pressure through small lines laid in the sewer itself, and made to transport large amounts of shredded refuse to the waste water treatment plant. There known processes, modified as necessary, might be used to stabilize the material and so make it more acceptable for long-term storage on the land or for discharge to the sea.

6. It is conceivable that the reuse of many components of refuse may require intermediate processing rather than simple salvage and recycling. For example, a sand derived from glass bottles might be usable in ornamental concrete or in the manufacture of fiberglass, whereas neither industry could use old bottles directly. It is further conceivable that raw materials for some industry as yet undeveloped might be derived from the processing or fractionation of major components of solid wastes.

7. The full potential of known technology has not been realized in solid wastes management for a number of reasons ranging from neglect to economics. To explore such potential the adaptability of current technology to the handling of community-wide wastes should be investigated, with special attention to the unit processes and design parameters necessary for successful and economic application of such technology. In addition, improvement of present methods is necessary to meet such emerging social objectives as resource conservation, clean air and water per se, quality of environment, etc.

8. The problem of solid wastes will not be resolved by some great scientific breakthrough akin to splitting of the atom; and no single solution suited to all communities is in prospect. Nevertheless there is need for, and prospects of, imaginative and ingenious ways of adapting known principles to the improvement of technologies which in various combinations will provide economical and socially acceptable solid wastes management to the urbanized community.

9. The range of possible methods of managing solid wastes is described by the seven major types of activity shown in Figure 1. As indicated in the figure there will always be some residue which will return to the "sink," i.e., the land or the ocean. The goal of solid wastes management in general will be the minimizing of the volume of this waste stream. All present technologies, as well as foreseeable future ones, for dealing with the total mass of solid wastes or selected fractions of it fit well into the seven categories noted. Typical current examples of each type are shown in the figure.

10. In the past, public health concern for solid wastes management have been largely those of vector control, air pollution, and perhaps, the effect of leachings on ground water quality. The result is that little is known concerning the levels of toxic compounds resulting from current methods of wastes disposal, or from proposed modifications of such methods. Toxic metals, particulate matter, gases, and vapors from incineration; virus or other vectors of disease in compost or sludges from animal manures, agricultural wastes, and human sewage; and the contribution of wastes management to the stresses of urban life, are all a part of the problem of solid wastes management. Although difficult to isolate from other factors in urban life there is no question that handling refuse in the home, transporting it through the streets, and concealing it somewhere in the physical environment of man adds to the stress of urban living. In some cases the citizen is outraged by affronts to his aesthetic sense or indignant over filling of shoreline areas; in others there is definite danger to health through vectors or air pollution.

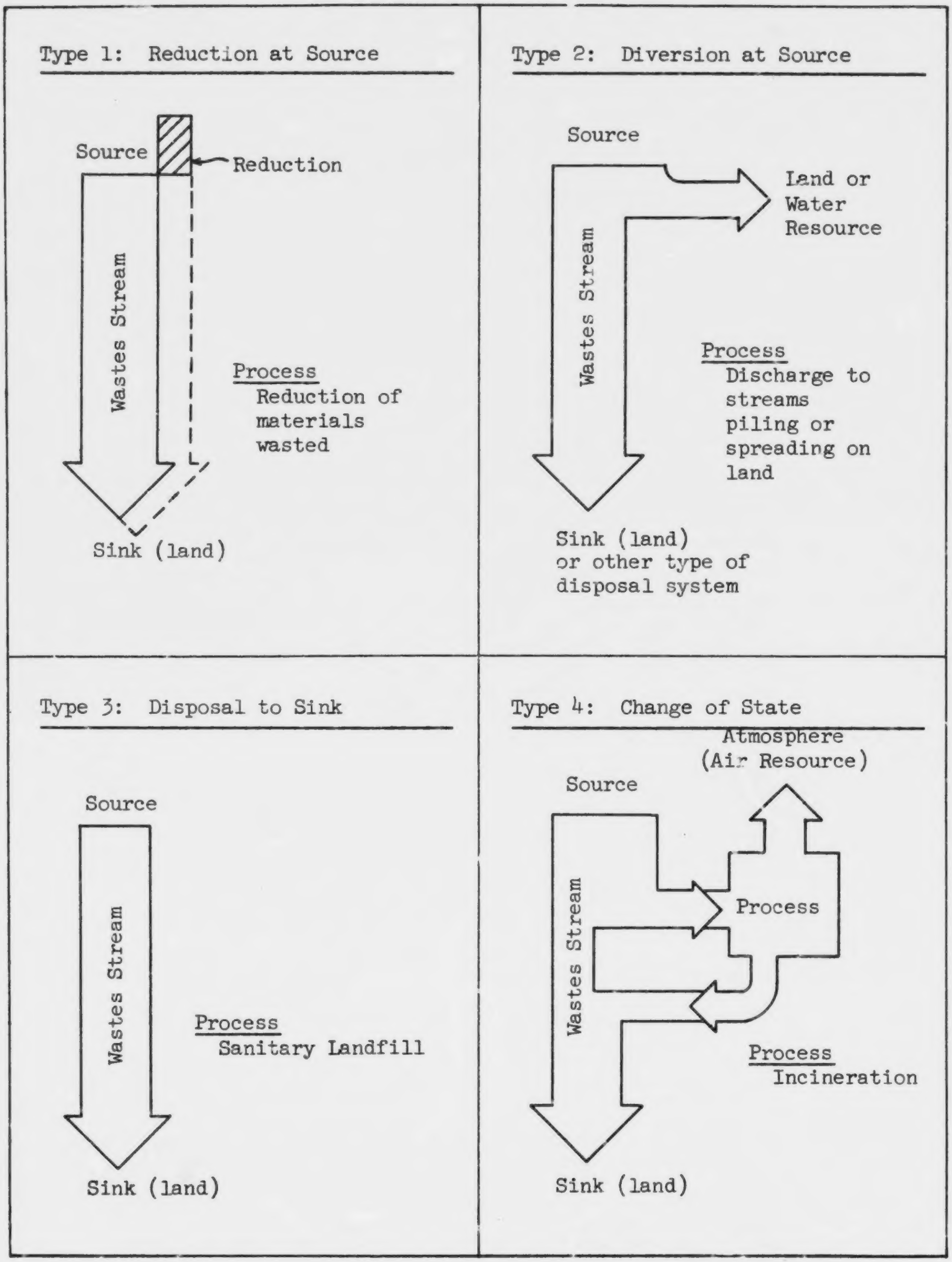

Type 1: Reduction at Source
Source
Reduction
Wastes Stream
Process
Reduction of materials wasted
Sink (land)
Type 2: Diversion at Source
Source
Land or Water Resource
Wastes Stream
Process
Discharge to streams piling or spreading on land
Sink (land) or other type of disposal system
Type 3: Disposal to Sink
Source
Wastes Stream
Process
Sanitary Landfill
Sink (land)
Type 4: Change of State
Atmosphere (Air Resource)
Source
Process
Wastes Stream
Process
Incineration
Sink (land)

FIGURE I. TYPES OF WASTE DISPOSAL SYSTEMS

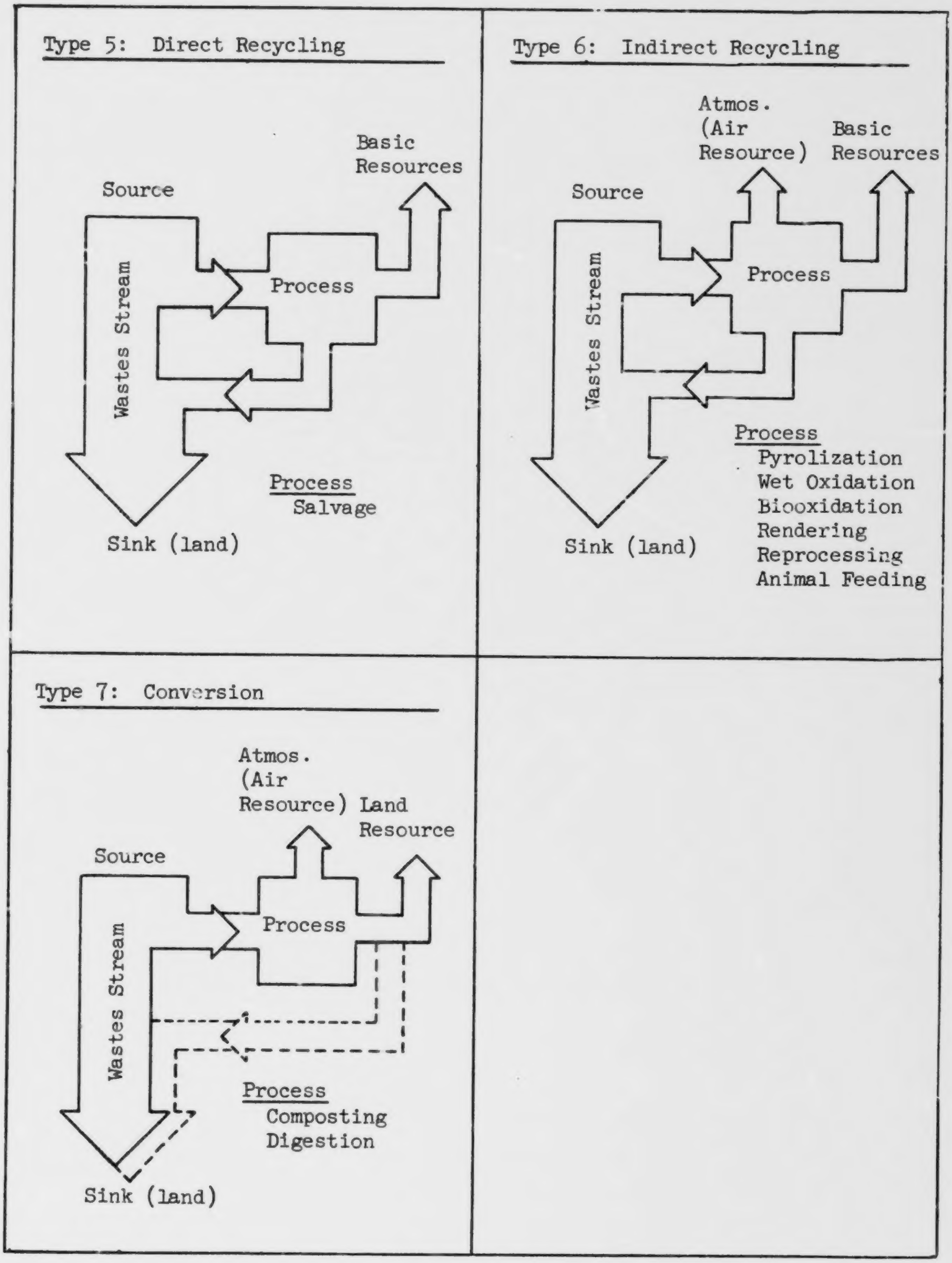

Type 5: Direct Recycling
Basic Resources
Source
Process
Wastes Stream
Process
Salvage
Sink (land)
Type 6: Indirect Recycling
Atmos. (Air Resource)
Basic Resources
Source
Process
Wastes Stream
Process
Pyrolization
Wet Oxidation
Biooxidation
Rendering
Reprocessing
Animal Feeding
Sink (land)
Type 7: Conversion
Atmos. (Air Resource)
Land Resource
Source
Process
Wastes Stream
Process
Composting
Digestion
Sink (land)

FIGURE I. Continued

Noise and traffic congestion are increased by the refuse handling operations; and no one wants to reside next door to a disposal operation.

Consideration of the impact on man's physical and mental health must therefore be a factor in the planning as well as in the technology of wastes management.

OBJECTIVES OF STUDY

The general objective of the study is to contribute, through research and research participation, significant advances in knowledge of the systems and technology, as well as informed professional personnel, needed in managing solid wastes in a manner which minimizes their effects in degrading the human environment and in inhibiting man's use of the earth's natural resources. Pursuant to this general objective the research program is directed to several more specific goals, including:

1. To bring the competence of people in the wide variety of disciplines involved in planning, financing, and administering a community into effective combination with that of engineers and environmental health specialists in seeking solutions to problems in solid wastes management which are technically sound, economically feasible, and politically and socially acceptable.
2. To bring the techniques of modern operations research to bear upon the organizational problems of managing solid wastes on an area-wide or community-wide basis; and on the physical and logistic problems of collecting, transporting, and disposing of wastes.
3. To seek through experiments and other research techniques improvements in conventional methods of wastes disposal and the development of new procedures for reclaiming or recycling fractions of the refuse mass.
4. To identify and seek answers to problems involving man's health and well being that may be associated with solid wastes and related to his use of land, water, and air resources.
5. To develop, through participation in research, greater understanding and knowledge on the part of engineers, planners, administrators, economists, public health specialists, and others who are confronted with the problem of solid wastes management in the course of their professional service to the modern urban-industrial-agricultural community.
6. To insure, through close coordination and effective communication with public and private agencies, the pertinence of research to real problems and the prompt availability of the results of research to professional practitioners.

ORGANIZATION FOR STUDY

Four faculty investigators representing the College of Engineering and the School of Public Health (Sanitary Engineering Research Laboratory) on the Berkeley campus and the departments of Civil Engineering and Agricultural Engineering on the Davis campus, were responsible for the management of the research program. In the conduct of the research these individuals were assisted by six additional participating faculty members responsible for guiding specific research teams and an additional six faculty members interested in facets of the program currently beyond the budgetary provisions but expected to be activated in future years.

During the report period (1966-67) one faculty investigator was on Sabbatical leave from the University but engaged in an intensive study of composting — one of the important technological aspects of the program. The remaining three faculty investigators and the six additional faculty members actively engaged in research teams served as a Board of Directors to guide and coordinate the research activities. In this they were assisted by a full-time project coordinator and a staff engineer. The Board met regularly at two-week intervals to review, discuss, and redirect the research effort as deemed necessary. Each meeting of the Board was attended and participated in by the professional personnel and graduate students participating in the program, and by additional graduate students pursuing group study of solid wastes, for formal University course credit. The general organization for the research program herein reported, together with the participating personnel is outlined schematically in Figure 2.

A breakdown of the classes and disciplines of personnel involved during the report period and anticipated for the future is presented in Table 1.

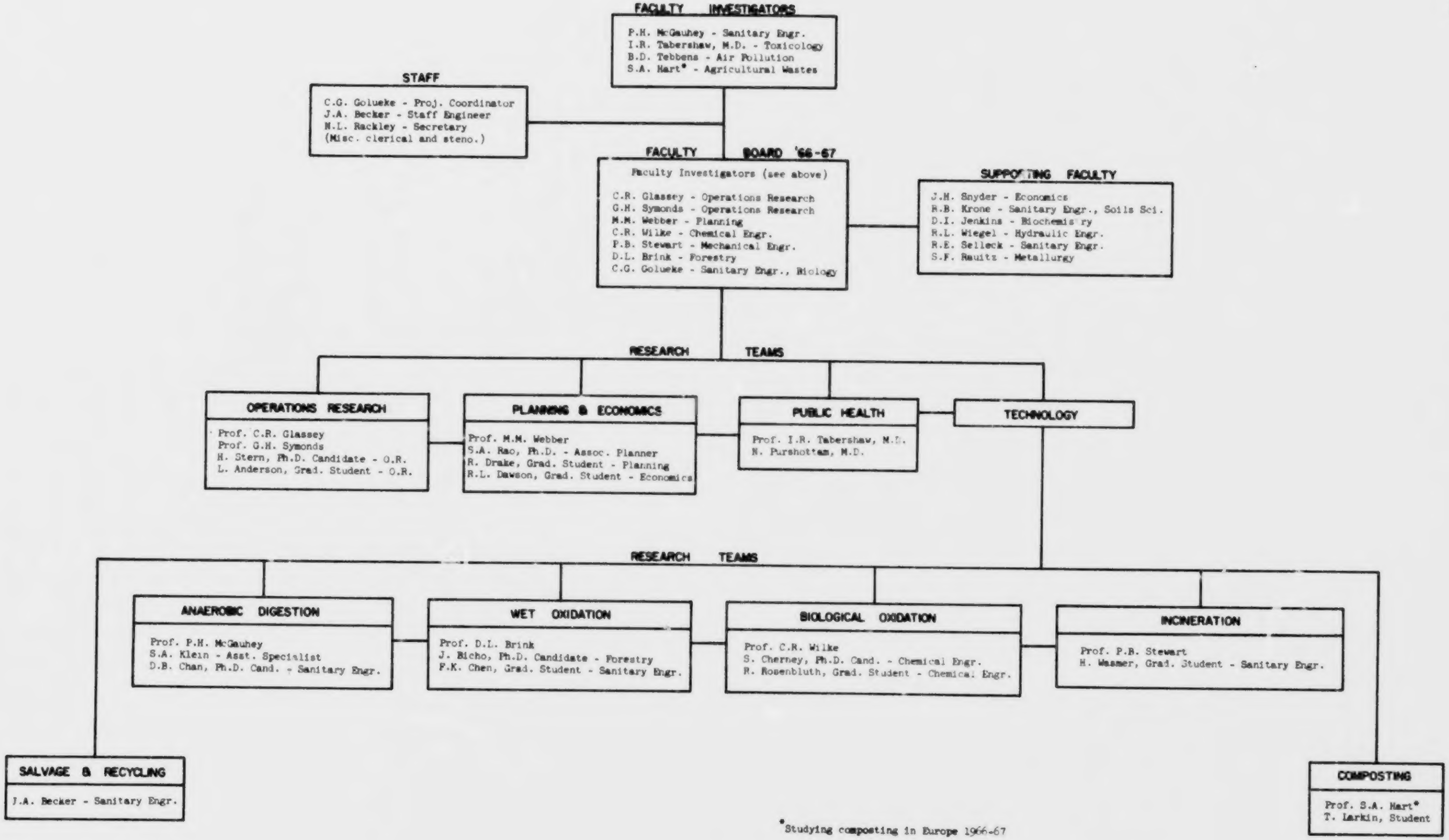
During the period of study herein reported (1966-67) the organizational structure proved to be so satisfactory and effective that it is expected to be continued during the 1967-68 period, for which funds are available, and farther into the future if financial support of the program develops. The values shown in Table 1 reflect the actual number of participants during the report period. Identification of the discipline involved may be made from Figure 2. As indicated in footnotes to the table it is anticipated that the economist serving in an advisory role in 1966-67 will in 1967-68 lead a research team closely integrated with the Planning and Operations Research teams. At the same time a reduction in professional research personnel will be offset by an increase in graduate student participation. The total number of graduate student participants further rises because of increased budgetary support in 1967-68. Subject to funding, the entire faculty group will become engaged on active research teams in 1968, adding such facets to the program as are important at that time. Present expectations are that these will include such areas as public administration and such technological problems as hydraulic transport, diffusion of solid wastes in ocean waters, and management of the metals component of refuse.

Cooperation with other federally and state financed projects on solid wastes management is a feature of the organization for study. Through a cooperative arrangement with the California State Department of Public Health the type of information required by the University research teams is included in questionnaires being used by the Department in its state-wide survey and its demonstration project at Fresno, California — both financed by the Public Health Service. A similar arrangement with the PHS makes available to the University group the results of a survey of industrial solid wastes being conducted by the Food Machinery Corporation under a federal grant. Thus only one group seeks information and so improves the degree of cooperation of the numerous public and private agencies from which data are needed.

To insure a constant two-way flow of information the project coordinator serves on the Advisory Board of the State Health Department's solid waste program, and frequent staff level discussions are arranged. In addition, good working relationships are maintained with numerous public and private agencies.

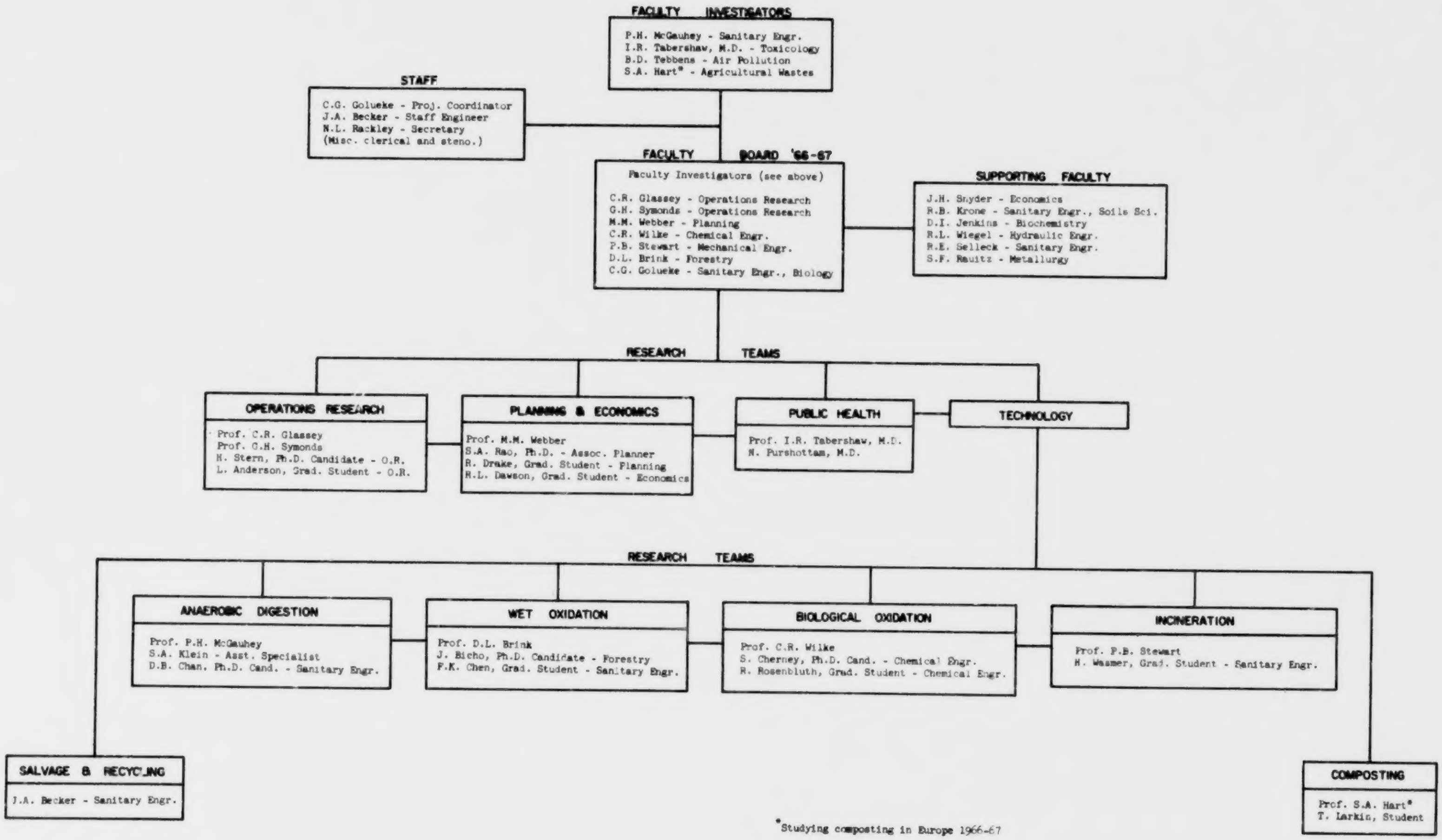
PLAN OF RESEARCH

Pursuant to the general and specific objectives of the study, the research program was designed to be conducted in two essentially sequential phases: (I) data collection and evaluation, and (II) definitive research. It was anticipated that during the first phase all participants in the program would function as a single research team to become fully acquainted with all aspects of the solid wastes problem and to collect and evaluate data on current technology and management techniques. Specific activities of the group scheduled for this phase included:


FACULTY INVESTIGATORS
P.H. McGauhey - Sanitary Engr.
I.R. Tabershaw, M.D. - Toxicology
B.D. Tebbens - Air Pollution
S.A. Hart* - Agricultural Wastes
STAFF
C.G. Golueke - Proj. Coordinator
J.A. Becker - Staff Engineer
N.L. Rackley - Secretary
(Misc. clerical and steno.)
FACULTY BOARD '66-67
Faculty Investigators (see above)
C.R. Glassey - Operations Research
G.H. Symonds - Operations Research
M.M. Webber - Planning
C.R. Wilke - Chemical Engr.
P.B. Stewart - Mechanical Engr.
D.L. Brink - Forestry
C.G. Golueke - Sanitary Engr., Biology
SUPPORTING FACULTY
J.H. Snyder - Economics
R.B. Krone - Sanitary Engr., Soils Sci.
D.I. Jenkins - Biochemistry
R.L. Wiegel - Hydraulic Engr.
R.E. Selleck - Sanitary Engr.
S.F. Rauitz - Metallurgy
RESEARCH TEAMS
OPERATIONS RESEARCH
Prof. C.R. Glassey
Prof. G.H. Symonds
H. Stern, Ph.D. Candidate - O.R.
L. Anderson, Grad. Student - O.R.
PLANNING & ECONOMICS
Prof. M.M. Webber
S.A. Rao, Ph.D. - Assoc. Planner
R. Drake, Grad. Student - Planning
R.L. Dawson, Grad. Student - Economics
PUBLIC HEALTH
Prof. I.R. Tabershaw, M.D.
N. Purshottam, M.D.
TECHNOLOGY
RESEARCH TEAMS
ANAEROBIC DIGESTION
Prof. P.H. McGauhey
S.A. Klein - Asst. Specialist
D.B. Chan, Ph.D. Cand. - Sanitary Engr.
WET OXIDATION
Prof. D.L. Brink
J. Bicho, Ph.D. Candidate - Forestry
F.K. Chen, Grad. Student - Sanitary Engr.
BIOLOGICAL OXIDATION
Prof. C.R. Wilke
S. Cherney, Ph.D. Cand. - Chemical Engr.
R. Rosenbluth, Grad. Student - Chemical Engr.
INCINERATION
Prof. P.B. Stewart
H. Wasmer, Grad. Student - Sanitary Engr.
SALVAGE & RECYCLING
J.A. Becker - Sanitary Engr.
COMPOSTING
Prof. S.A. Hart*
T. Larkin, Student

*Studying composting in Europe 1966-67

FIGURE 2. ORGANIZATION OF STUDY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COMPOSTING
Prof. S.A. Hart*
T. Larkin, Student

*Studying composting in Europe 1966-67

FIGURE 2. ORGANIZATION OF STUDY

TABLE 1

SUMMARY OF PARTICIPANTS IN THE PROGRAM

Type of Personnel	Number of Participants					
	1966-67 (Actual)		1967-68 (Budgeted)		Future (Anticipated)	
	Individuals	Disciplines	Individuals	Disciplines	Individuals	Disciplines
Professors active on research teams	11	9	12[a]	10	18[b]	15
Professors, advisory	6	5	5	4	0	-
Professors, total active plus advisory	17	14	17	14	18[b]	15
Professional research	5	5	3	3	6	6
Graduate students on research teams	10	6	16	9	20	13
Graduate students on individual study assignments	15 (- - - - - -	3 - - - - - -	Estimated 12 - - - - - - Not	4 Budgeted - - -	c - - - - - -	c - - - - - -)
Clerical and misc. (including undergraduate students)	3	-	4	-	5	-

[a] Economist in advisory group will become active on research team 1967-68.

[b] 1966-67 Faculty Board and Supporting Faculty plus representative of Public Administration will become active on research teams.

[c] To be determined.

1. Collection and evaluation of published information on the technology and management of solid wastes.
2. Establishment of an information retrieval system.
3. Interviews and discussions with officials and operating personnel of public and private agencies concerned with solid wastes management in the San Francisco Bay and Los Angeles areas.
4. Collection and evaluation of data on the composition and amount of the various fractions which in combination constitute the overall solid wastes of a community.
5. Definition and coordination of discrete areas of research to be undertaken in Phase II by the individual research teams.

It was expected that by the end of the first year of study Phase I would be completed and Phase II sufficiently advanced that its direction could be clearly defined and evaluated; further, that the individual research teams would continue data collection and evaluation in their specific areas and initiate experimental work at the appropriate time. Thus not all aspects of the definitive research were expected to begin simultaneously or at the same level of experimental effort. However, all were expected to fit into and be an integrated part of an overall regional evaluation model capable of generating management systems on the basis of waste generating inputs.

During the period reported research proceeded in accordance with this plan and at a somewhat more rapid pace than was originally expected.

PART II
PHASE I OF THE INVESTIGATION

II. DATA COLLECTION AND EVALUATION

LITERATURE SURVEY AND INFORMATION RETRIEVAL

The first two aspects of Phase I described in the preceding section of this report were begun in June 1966. During the following six months more than 500 documents dealing with solid wastes were collected and abstracted. The abstracts, rather detailed in nature, were typed on 6.5 in. x 7.5 in. edge-notched cards. The cards were then codified and a manual information retrieval system [1] was set up.

An evaluation of the literature surveyed, with particular reference to its pertinence to the overall problems of solid waste management, as contrasted with details of technology, revealed some interesting facts.

Papers

Generally, published papers concerned with refuse disposal are written in a "popular" style, i.e., nontechnical and slanted toward the "layman." Those concerned with agricultural wastes, especially the animal manures, are more technical in nature. Prior to the 1960's composting seemed to be the most popular subject of papers on refuse disposal. Occasionally an article on landfill would appear, in which case the subject usually would be on the advantages of abandoning an open dump disposal operation in favor of a sanitary landfill. Articles on the management of agricultural wastes were concerned more with handling than with disposal, probably because agricultural waste disposal did not constitute the problem which it does now. In those days individual operations were not as big as today's and satisfactory disposition of most of the agricultural wastes generated by many of the operations could be made by spreading on adjacent fields.

As time advanced in the 1960's, the number of published papers on refuse disposal increased. However, the papers continued to remain mostly "popular" in style. Papers of a general nature were less common than those of a particular nature. The articles usually dealt with a description of a particular installation or a particular community. Incineration received more and more attention, while landfill constituted a close second. On the other hand, the use of composting declined as a subject of papers, and authors once blindly optimistic became more skeptical, and downright pessimistic in many instances. Authors of papers on the management of agricultural wastes became quite prolific and the style of their papers continued to be technical.

Reports

As was true with papers published prior to the 1960's, reports on the handling of agricultural wastes far outnumbered those on urban wastes. In fact, before the 1960's, reports on refuse disposal and management were quite rare. The reason for the paucity undoubtedly was the scarcity of money to conduct the research on which reports are based. Some of these reports are listed as numbers [2] through [9] in the REFERENCES. Noteworthy among them are those published by the International Research Group on Refuse Disposal [7].

During the 1960's reports on wastes management became more numerous, the increase being directly proportional to the increase in influx of federal funds into research on the subject. Now the number is legion. Especially worth mentioning is the series of reports issued by the Incineration Committee of the Division of Process Industries (ASME), the National Sanitation Foundation, and by various regional groups and public agencies. Randomly selected examples of these reports are listed as numbers [10] through [17] in the REFERENCES. The subject matter of the reports ranges from surveys of existing practices in solid wastes management to comprehensive planning for environmental health, and from waste disposal methods to legal implications.

Journals

Prior to the 1960's, American Journals devoted solely to Solid Wastes Management were limited to Compost Science and to the Refuse Removal Journal. As the name implies, Compost Science was and is concerned chiefly with various aspects of composting, although it did occasionally treat other aspects of solid wastes management, but only insofar as they could be related to composting. The Refuse Removal Journal is primarily a trade journal and is more concerned with the collection and haul aspects of waste management than with disposal technology. It is a strong advocate of landfill and incineration; composting finding little favor with its editorial staff.

Public Cleansing, a journal published in England, has been in circulation for years. The journal covers all aspects of solid wastes management and invariably contains interesting and informative articles.

Although no new journals devoted exclusively to solid wastes appeared in the 1960's, the problem of solid wastes management began to receive more and more attention, and finally achieved a position approaching that of water supply and waste water treatment in the more widely distributed periodicals. Thus The American City and Public Works generally have a section devoted to solid wastes. Among other commonly-read periodicals whose orientation is toward the environmental sciences and in which solid wastes are receiving increasing attention are Environmental Science and Technology, and Western City. Compost Science and the Refuse Removal Journal continue to be geared to solid wastes management.

From the trends observed in the survey of literature it seems evident that the pre-1960 situation of the scarcity of papers and reports on solid wastes management is changing to one of abundance; and as is the case with so many of the newly popular subjects, will eventually develop into one of superabundance.

PERSONAL INTERVIEWS

Personal interviews with managing and operating personnel involved in solid waste handling and disposal was a particularly important aspect of Phase I of the project as they served to orient the members of the research group— many of whom hitherto had had no direct contact with refuse other than as a householder. This orientation served both to give an idea of the actual nature of refuse as it exists at the disposal site and to promote an understanding of the day-to-day problems confronting officials charged with the task of managing refuse. It was particularly revealing of the extent of public apathy and the nature of pressures from special interests.

The investigator group visited a total of 12 refuse disposal sites, all utilizing the landfill method since no refuse incinerators are in operation at present in either the San Francisco Bay or Los Angeles area. Practice in these 12 situations ranged from that of meeting all the criteria of a well-operated disposal method to that of the slightly improved open dump. Salvage operations were also observed. These ranged from the sorting and processing of tin cans to the classification and bailing of paper. The can operation involved the use of a specially designed machine into which unsegregated refuse was dumped into one end and the separated cans and refuse were discharged at the opposite end. Two or three passes had to be made to bring about satisfactory separation.

The officials of 14 public and private agencies located in the San Francisco Bay and Los Angeles areas were visited. In each case the agency was either directly responsible for waste management or concerned with it as a regulatory agency or as one having a special mission involving refuse. Responsibility for waste management was found to rest in a variety of departments, the identity of which varied from agency to agency — from the county health department in one instance to the county highway department in another. The impression gained from the interviews was that long-range plans for waste management have been, are, or are being drawn up by the professional personnel but that the changes for the implementation of these plans generally are not good until public feeling is aroused and exerted.

The investigator group was impressed with dedication and the generally foresighted character of the personnel involved in wastes management despite the evident lack of cooperation that is their common lot. The interviews drove home the need for a broad attack on the waste management problem, one that would encompass not only technological aspects but the sociological as well.

CHARACTERISTICS AND AMOUNTS OF SOLID WASTES

Introduction

In parallel with the survey of literature and establishment of an information retrieval system, an intensive review was made of the amount of wastes of various categories generated in a community and of the components of each. Literature search, personal interviews, case histories, and field analyses were all utilized in efforts to get data on the kinds and nature of material appearing as solid wastes. Of major importance were cooperative arrangements with the California State Department of Public Health and the Public Health Service, under which data on municipal and industrial wastes generated in ongoing demonstration projects in California became available to the research project herein reported. As improbable as it might seem from a rational viewpoint, long experience with refuse disposal has not produced information on the composition of solid wastes in the detail now needed for management purposes. For this deficiency there are several reasons, including:

1. Traditional concepts of management.
2. Scope of concern with solid wastes.
3. Dislocation of systems.
4. Change in industrial technology.
5. Cultural and sociological changes in America.

These and related factors are so closely intertwined that they are not separated sharply for discussion herein. Instead, attention is called to some of their separate or combined effects.

Disruption of traditional concepts of management, with resulting need for new approaches, has come about in recent years partly because of an increase in the variety of wastes with which the public found it necessary to become concerned. Historically, refuse disposal by any but the most primitive methods of dumping on land or open burning has been concerned with refuse collected from individual households and commercial establishments within a city. But, as noted in a previous section, in the modern community industrial and agricultural residues (cannery wastes, animal manures, demolition and construction debris, and automobile bodies and other junk) have also become a part of the residue to be managed in a manner suited to man's health, aesthetic, and social objectives. Thus, by extending the scope of the problem there has resulted a dislocation of technology as well as of the jurisdictional and physical systems of wastes management.

Dislocation of past inadequate systems of waste management is further rendered critical by the sheer magnitude of the material to be handled. The traditional 2 pounds per capita per day has now reached an estimated 6-8 pounds in many localities. At such a rate the refuse from 130 million urban Americans is enough each year to cover 50 square miles with a compacted fill 10 feet deep.

Further dislocation of technology derives from the changing nature of municipal refuse itself. A historical spendthrift attitude toward resources is reflected both in a disconcern for wastes and a proliferation of such residues. So great were our national resources that we became an affluent society in spite of our wastage; and once the natural harvest of the earth had been reaped by simple extractive enterprise, American energy and inventiveness was turned to a sophisticated industry capable of maintaining and extending that affluence. One by-product of this development has been the never-ending variety of new waste products from our industry. With opulence also grew the desire for greater convenience of living. The result is disposable containers, nonreturnable bottles, short-lived plastic objects, urban renewal, planned obsolescence, and all the other gadgetry and concepts which magnify the amount as well as the types of wastes which must be managed within a community. Garbage grinders now discharge to the sewers some 30% to 80% of organic matter once collected as solid wastes; plastics and nonreturnable containers have increased in volume, with profound effects on combustibility and degradability of refuse; metal cans without a salvable tin content are coming into use; and industry creates some 2,000 new products each year. Furthermore, the domestic economy has come to depend to a considerable degree upon the continued replacement of goods.

Need for Refuse Analysis Studies. As long as technology remained relatively simple, there was no important need to obtain accurate estimates of the relative amounts of various components of solid wastes. For landfill, volume of the mixed refuse and its compactability are the important factors. For incineration, the percentage of noncombustibles and the problem of separating these out are most important. For salvage, the amount of specific salvable items and the cost of removing them from the mass are important. It is only where management of solid wastes makes the objective of returning materials to the resources of the nation by some of the more complex methods illustrated in Figure 1 (page 8), that a need is felt for a greater knowledge of the composition of refuse. Since these are the objectives of today and tomorrow rather than of yesterday, it is to be expected that detail is lacking on the actual weights and volumes of specific components.

The general values so repeatedly quoted, including those stated in the previous paragraph, are based more on estimates than on actual observations. Those which are based on actual observation usually are the results of isolated or 'one-time-only' studies. The validity of the more general of these findings is unknown because of the absence of extensive and prolonged surveys. The need for accurate information on these subjects is quite obvious. To rationally design a management system, including collection, technology, and reclamation, a prime requisite must be that the nature and volume of the material to be managed is known. In addition, the effects of time (as brought about by changes in standard of living, economy, living habits, and neighborhood patterns) must be known so that reliable predictions can be made, and hence make it possible to design long-term management systems. Climatological and large-scale regional characteristics also exert an influence on the nature of wastes. Thus, a management system suited to one section of the United States or to a given geographical location would not necessarily be applicable to another section or location.

General Estimates of Refuse Composition. Reported estimates on the size of the garbage fraction of refuse range from 5% to 15% [18-26]. Reported values for the ratios of combustible-to-noncombustible rubbish also vary, the range in these classifications extending from 15% to 25% for the noncombustibles and 64% to 75% for the combustibles. A range of reported values also exists for breakdowns of these totals. Examples of the more common constituents are: paper 42% to 57%, metals 1.5% to 8%, glass 2% to 15%, rags 0.6% to 2%, garden debris 10% to 12%, and ashes 5% to 19% [18-26]. As might be expected, the low value for ashes was found in a report on the average composition of municipal wastes in California [18]. Despite in various social, climatic, and geographic regions at different times and seasons of the year. The information used in arriving at these denominators was gleaned from several reports and publications [19,26,31-35]. With this information at hand, it was possible to give weight to specific components for values where agreement exists and to compensate for strictly local conditions and for the changing nature of wastes.

TABLE 2

ESTIMATE OF GROSS REFUSE GENERATION
IN SANTA CLARA COUNTY (1967)

Type	lb/capita/day	tons/year x 10^3
Domestic	3.5	627
Industrial	0.5	89.4
Agricultural	1.7	304
Special	2.3	415
Total	8.0	1,435.4

Domestic Wastes. Table 3 presents an estimated breakdown of domestic waste production into its major components, the percentage of the total weight constituted by these components, daily per capita production, and total annual production. A per capita production of 8 lb/day, of which 44 percent is domestic refuse, was assumed in arriving at the estimated values.

TABLE 3

ESTIMATE OF COMPONENTS OF DOMESTIC REFUSE
IN SANTA CLARA COUNTY (1967)

Classification	Percentage of Total	lb/day	tons/yr
Garbage	12	0.42	75,240
Rubbish			
Paper	50	1.75	313,500
Wood	2	0.07	12,540
Cloth	2	0.07	12,540
Rubber	1	0.04	6,270
Leather	1	0.04	6,270
Garden Wastes	9	0.31	56,430
Metals	8	0.28	50,160
Plastics	1	0.04	6,270
Ceramics & Glass	7	0.24	43,890
Nonclassified	7	0.24	43,890
Total	100	3.50	627,000

Industrial Wastes. Data on the types of wastes generated by industries in Santa Clara County were collected as a part of Phase I of this study. Estimates of the amounts of each of these types is being prepared by the Food Machinery Corporation (FMC) under terms of a Public Health Service demonstration grant. They were not available at this writing but will accrue to the study in due time. The collected data, however, do permit an evaluation of the relative waste-generating potential of various industries. Later, on the basis of the FMC data, the planning and economic research teams will be able to predict industrial waste production on the basis of statistical and census-type information available in any community.

According to a 1966 survey [36], 1,237 manufacturing firms are functioning in Santa Clara County. If the standard Industrial Classification Group Code [37] is followed, these firms fall into 28 major groups. These groups, together with the type of waste expected to be generated by each group, are listed in Table 4. The number of firms belonging to each group as well as the number of employees hired by them are presented in Table 5.

It may be expected that two types of solid wastes will be generated by the 28 major industrial groups listed in Table 5:

1. Wastes that are common to all types of industry.
2. Wastes that are peculiar to the individual industry by reason of the nature of the raw material processed and the product produced.

In the first grouping is included such items as wood, fiber, paper, metal, and plastic containers in which raw materials and supplies for maintenance and operation are received by the industry; scraps of metal, wood, paper, and plastics used by the industry in painting, crating, or otherwise preparing its product for shipment; and the normal debris from general housekeeping and operating and maintaining an industrial plant. In this latter category are such items as waste paper, floor sweepings, broken wooden pads, rubber tires, storage batteries, broken glass, and junk which results from obsolescence or breakage of equipment or equipment parts. Residues of paint, industrial chemicals, dyes, adhesives, and solvents remaining in discarded containers are likewise common to all industries, although the amount and kind varies from industry to industry and from plant to plant.

The type of wastes peculiar to individual industries is suggested in the summary as presented in Table 6.

In the foregoing list of solid wastes generated by specific industries residues from plating, pickling, painting, and similar operations have been included. For the most part these processes produce liquid residues which are managed separately from the solid wastes. Nevertheless, oils, paints, dyes, plating and pickling liquors, solvents, adhesives, etc. do appear on such solid wastes as metal cuttings, sawdust, paper, wood, cloth, and junk. Without adding to the amount of wastes to be managed, they might have a public health or nuisance significance in certain methods of disposal, hence their presence is noted in the list of industrial waste materials.

Agricultural Wastes. Although at present a large portion of agricultural wastes does not require special handling in Santa Clara County, inasmuch as it is left in the field, the time may soon come when even this fraction will have to be handled. For example, prunings now routinely burned in the field may have to be disposed of in some other fashion when air pollution legislation makes the practice illegal. When this comes to pass, it may be necessary to transport the prunings to some disposal site. Approximately 71 percent of agricultural wastes which do require special handling occurs in the form of animal manures and 29 percent in the form of prunings. In terms of tonnage, approximately 212,000 tons of animal manures and 88,000 tons of prunings must be disposed of annually in Santa Clara County. These numbers are the results of computations based on the size of the animal population as given in the records (1965-66) of the county of Santa Clara and the city of San Jose on reported manure production per animal [33], and on data on production

TABLE 4
PRINCIPAL EXPECTED WASTES FROM MANUFACTURING AND/OR PROCESSING INDUSTRIES[a]
SANTA CLARA COUNTY, CALIFORNIA

Code	Industry	Metals	Wood	Fiber, Natural & Synthetic	Paper	Leather	Glass & Ceramics	Plastic	Rubber	Garbage	Chemicals, Organic & Inorganic	Petroleum & Pairts	Mineral	Organic
17	Plumbing, Heating, & Air Conditioning	X	X	X	X		X	X	X			X	X	
19	Ordnance & Accessories	X	X	X	X		X	X	X			X		
19	Ordnance-Explosives	X	X	X	X			X			X	X		
20	Food & Kindred Products	X	X	X	X		X	X		X				X
22	Textile Mill Products	X	X	X	X			X	X		X			
23	Apparel & Other Finished Products Made from Fabrics & Similar Material	X	X	X	X	X	X	X						
24	Lumber and Wood Products	X	X	X	X			X				X		
25	Furniture, Wood	X	X	X	X	X	X	X				X		
25	Furniture, Metal	X	X	X	X	X	X	X	X			X		
26	Paper and Allied Products	X	X		X			X			X		X	
27	Printing, Publishing, & Allied Industries	X	X	X	X			X			X			
28	Chemical and Allied Industries	X	X	X	X		X	X	X		X	X	X	
28	Chemical, Explosives	X	X	X	X			X			X			
29	Petroleum Refining & Related Industries	X	X	X	X							X	X	
30	Rubber & Misc. Plastic Products	X	X	X	X			X	X				X	
31	Leather & Leather Products			X	X	X					X			X
32	Stone, Glass, & Glass Products	X	X	X	X		X						X	
33	Primary Metal Industries	X	X		X							X	X	
34	Fabricated Metal Products	X	X		X		X	X	X		X	X	X	
35	Machinery Except Electrical	X	X	X	X		X	X	X			X		
36	Electrical	X	X	X	X		X	X	X		X	X	X	
37	Transportation Equipment	X	X	X	X	X	X	X	X		X	X	X	
38	Professional, Scientific, and Controlling Instruments	X	X	X	X		X	X	X			X	X	
39	Misc. Manufacturing	X	X	X	X	X	X	X	X		X	X		

[a] Based on information contained in a 1966 report of FMC. See Reference [38].

TABLE 5

CLASSIFICATION OF MANUFACTURING FIRMS IN SANTA CLARA COUNTY, CALIFORNIA BY NUMBERS AND EMPLOYEE GROUPS[a]

Standard & Industrial Classification Group		Number of Firms	(A)	(B)	(C)	(D)	(E)	(F)
Code	Classification							
17	Plumbing, Heating & Air Conditioning	9	9					
19	Ordnance & Accessories	1					1	
19	Ordnance - Explosives	2		2				
20	Food & Kindred Products	145	64	38	35	8		
22	Textile Mill Products	1		1				
23	Apparel & Other Finished Products	23	22		1			
24	Lumber & Wood Products	21	18	2	1			
25	Furniture - Wood	44	38	6				
25	Furniture - Metal	15	13	2				
26	Paper & Allied Products	21	9	6	6			
27	Printing, Publishing & Allied Industries	166	137	22	6	1		
28	Chemical & Allied Industries	60	47	12	1			
28	Chemical - Explosives	1	1					
29	Petroleum Refining & Related Industries	9	4	5				
30	Rubber & Misc. Plastic Products	31	27	2	2			
31	Leather & Leather Products	3	3					
32	Stone, Clay & Glass Products	63	38	17	4	4		
33	Primary Metal Industries	22	15	6	1			
34	Fabricated Metal Products	123	96	20	5	2		
35	Machinery except Electrical	164	132	26	4	1	1	
36	Electrical - Tubes	5			4	1		
36	Electrical	145	74	31	29	5	6	
37	Transportation Equipment	38	29	7	1		1	
38	Professional, Scientific & Controlling Equipment	59	42	10	4	1	2	
39	Misc. Mfg. - Jewelry & Toys	22	21	1				
39	Misc. Mfg. - Nuclear Products	2		1			1	
39	Misc. Mfg. - Missiles	2				1		1
39	Misc. Mfg. - Industries	37	32	4	1			
	Total	1,234	871	221	105	24	12	1

Key to Number of Employees: (A) 1 - 25, (B) 26 - 100, (C) 101 - 500, (D) 501 - 2,000, (E) 2,001 - 10,000, (F) Over 10,000.

[a] Based on information contained in the 1966 report of the Food Machinery Corporation. See Reference [38].

TABLE 6

SOURCES AND TYPES OF INDUSTRIAL WASTES, SANTA CLARA COUNTY

Code	S. & I. C. Group Classification[a]	Waste Generating Processes	Expected Specific Wastes
17	Plumbing, Heating, Air Conditioning	Manufacturing and installation in homes, buildings, and factories	Scrap metal from piping and duct work; rubber, paper, and insulating materials; misc. construction and demolition debris
19	Ordnance and Accessories	Manufacturing and assembling	Metals, plastic, rubber, paper, wood, cloth, and chemical residues
20	Food and Kindred Products	Processing, packaging, and shipping	Meats, fats, oils, bones, offal vegetables, fruits, nuts and shells, and cereals
22	Textile Mill Products	Weaving, processing, dyeing, and shipping	Cloth and fiber residues
23	Apparel and Other Finished Products	Cutting, sewing, sizing, and pressing	Cloth and fibers, metals, plastics, and rubber
24	Lumber and Wood Products	Sawmills, mill work plants, wooden container manufacture, and manufacturing of misc. wood products	Scrap wood, shavings, sawdust; in some instances metals, plastics, fibers, glues, sealers, paints, and solvents
25	Furniture, Wood	Manufacture of household and office furniture, partitions, office and store fixtures, and mattresses	Those listed under Code 24, and in addition cloth and padding residues
25	Furniture, Metal	Manufacture of household and office furniture, lockers, bedsprings, and frames	Metals, plastics, resins, glass, wood, rubber, adhesives, cloth, and paper
26	Paper and Allied Products	Paper manufacture, conversion of paper and paperboard, manufacture of paperboard boxes and containers	Paper and fiber residues, chemicals, paper coatings and fillers, inks, glues, and fasteners
27	Printing and Publishing	Newspaper publishing, printing, lithography, engraving, and bookbinding	Paper, newsprint, cardboard, metals, chemicals, cloth, inks, and glues
28	Chemicals and Related Products	Manufacture and preparation of inorganic chemicals (ranges from drugs and soups to paints and varnishes, and explosives)	Organic and inorganic chemicals, metals, plastics, rubber, glass, oils, paints, solvents, and pigments
29	Petroleum Refining and Related Industries	Manufacture of paving and roofing materials	Asphalt and tars, felts, asbestos, paper, cloth, and fiber
30	Rubber and Miscellaneous Plastic Products	Manufacture of fabricated rubber and plastic products	Scrap rubber and plastics, lampblack, curing compounds, and dyes
31	Leather and Leather Products	Leather tanning and finishing; manufacture of leather belting and packing	Scrap leather, thread, dyes, oils, processing and curing compounds
32	Stone, Clay, and Glass Products	Manufacture of flat glass, fabrication or forming of glass; manufacture of concrete, gypsum, and plaster products; forming and processing of stone and stone products, abrasives, asbestos, and misc. non-mineral products	Glass, cement, clay, ceramics, gypsum, asbestos, stone, paper, and abrasives
33	Primary Metal Industries	Melting, casting, forging, drawing, rolling, forming, and extruding operations	Ferrous and non-ferrous metals scrap, slag, sand, cores, patterns, bonding agents
34	Fabricated Metal Products	Manufacture of metal cans, hand tools, general hardware, non-electric heating apparatus, plumbing fixtures, fabricated structural products, wire, farm machinery and equipment. coating and engraving of metal	Metals, ceramics, sand, slag, scale, coatings, solvents, lubricants, pickling liquors
35	Machinery (except electrical)	Manufacture of equipment for construction, mining, elevators, moving stairways, conveyors, industrial trucks, trailers, stackers, machine tools, etc.	Slag, sand, cores, metal scrap, wood, plastics, resins, rubber, cloth, paints, solvents, petroleum products
36	Electrical	Manufacture of electric equipment, appliances, and communication apparatus, machining, drawing, forming, welding, stamping, winding, painting, plating, baking, and firing operations	Metal scrap, carbon, glass, exotic metals, rubber, plastics, resins, fibers, cloth residues
37	Transportation Equipment	Manufacture of motor vehicles, truck, and bus bodies, motor vehicle parts and accessories, aircraft and parts, ship and boat building and repairing motorcycles and bicycles and parts, etc.	Metal scrap, glass, fiber, wood, rubber, plastics, cloth, paints, solvents, petroleum products
38	Professional, Scientific, Controlling Instruments	Manufacture of engineering, laboratory, and research instruments and associated equipment	Metals, plastics, resins, glass, wood, rubber, fibers, and abrasives
39	Miscellaneous Manufacturing	Manufacture of jewelry, silverware, plated ware, toys, amusement, sporting, and athletic goods, costume novelties, buttons, brooms, brushes, signs, and advertising displays	Metals, glass, plastics, resins, leather, rubber, composition, bone, cloth, straw adhesives, paints, and solvents

[a] Standard Industrial Classification Group Code. See Reference [36].

of prunings published in various local reports [30,33,34]. Other information herein reported was gathered from:

1. The files of the county of Santa Clara Public Health Department, Vector Control Division;
2. Visits to the University of California Agricultural Extension Service, Santa Clara County;
3. The city of San Jose Public Health Department, Milk Inspection Division;
4. County of Santa Clara 1965 Agricultural Report; and
5. Visits to livestock producers in the county.

The principal agricultural wastes generated in the county are animal manures – chicken and cattle, animal carcasses, grape and orchard prunings, crop harvesting residues, greenhouse horticultural wastes, and pesticide containers. (The pesticide containers are listed as an agricultural waste because these are used and are discarded in agricultural operations, i.e., their use has become an essential feature of agricultural practice.) Problems arising from presently improper management of these wastes are air pollution in operations involving the incineration of the wastes, breeding of insects and rodents as a result of improper storage, and generation of offensive odors through improper handling. A distinct health problem arising from the presence of pesticide containers is the release of the toxic materials remaining as residue in the cans to the surrounding environment.

Animal Manure: The major portion of the manure that must be handled in Santa Clara County originates in 61 dairies, 60 chicken ranches, and one feed lot. The total animal population of the 61 dairies is approximately 8,520. These animals produce about 99,600 tons (moisture content - 84%) of manure per year. The distribution of this waste generation in the county is indicated by the data listed in Table 7 (see Figure 3 for identification of planning areas). Although a few of the dairies sell or dispose of the manure they produce, the majority have the manure hauled away by private collectors, usually for use on truck gardens in the Salinas area.

At present only one feed lot is in use in Santa Clara County (San Martin area, see Figure 3). The lot is used as a site for fattening steers for the market, and as such, augments the natural pasture when it is not in full use, viz., from late summer until early spring – about nine months per year. According to the operator, approximately 17,000 cattle were fed on the lot during this nine-month period in the past year. Assuming an average residence time of three months per steer, the year-round average would have been 5,666 steers. Again assuming that each steer produces 60 lb (wet weight) of manure per year, the year's production on the lot was 510 tons wet weight or 81.6 tons dry weight. Unfortunately, the arrangement of the pens on the feed lot is such that manure is allowed to accumulate rather than be trampled and thus promote its dehydration. A consequence of this typically poor arrangement is the development of a fly problem so severe as to warrant action by the County Health Department. The visual amenities are met by interposing a white picket fence between the nearby highway and the barbed wire fence of the lot itself. The picket fence partially conceals the animals and the manure from the public view. With respect to disposal, periodically the manure is hauled to Salinas for use in truck gardens.

Fixty-six of the chicken ranches are devoted primarily to egg production and four to raising fryers. The 56 egg producers have a layer and brooder population of 1.2 million. The four fryer producers average about 27,500 birds/year (about 4-1/2 'generators'/year). The distribution of this waste generation in the county is indicated by the data listed in Table 8 for the several planning areas presented in Figure 3. The egg laying age for the layers begins at about six months and end at 30 months. At the end of their optimum egg laying age, they are sold to

TABLE 7

DISTRIBUTION OF DAIRY MANURE GENERATION IN SANTA CLARA COUNTY

Planning Area	No. Animals	Percent of Total	Wet Weight tons/yr	Dry Weight[a] tons/yr	Volume[b] cu yd/yr
1	744	8.7	8,670	1,384	14,430
7	390	4.6	4,580	732	7,630
11	40	0.5	498	80	830
13	611	7.2	7,180	1,146	11,930
14	530	6.2	6,180	987	10,290
15	140	1.6	1,593	255	2,655
16	400	4.7	4,684	748	7,800
18	531	6.2	6,180	987	10,290
19	660	7.7	7,670	1,226	12,770
20	400	4.7	4,685	748	7,800
21	205	2.4	2,390	382	3,985
22	2,008	23.6	23,485	3,758	39,150
23	1,761	20.7	20,610	3,296	34,350
24	100	1.2	1,195	191	1,990
Total	8,520	100.0	99,600	15,920	166,000

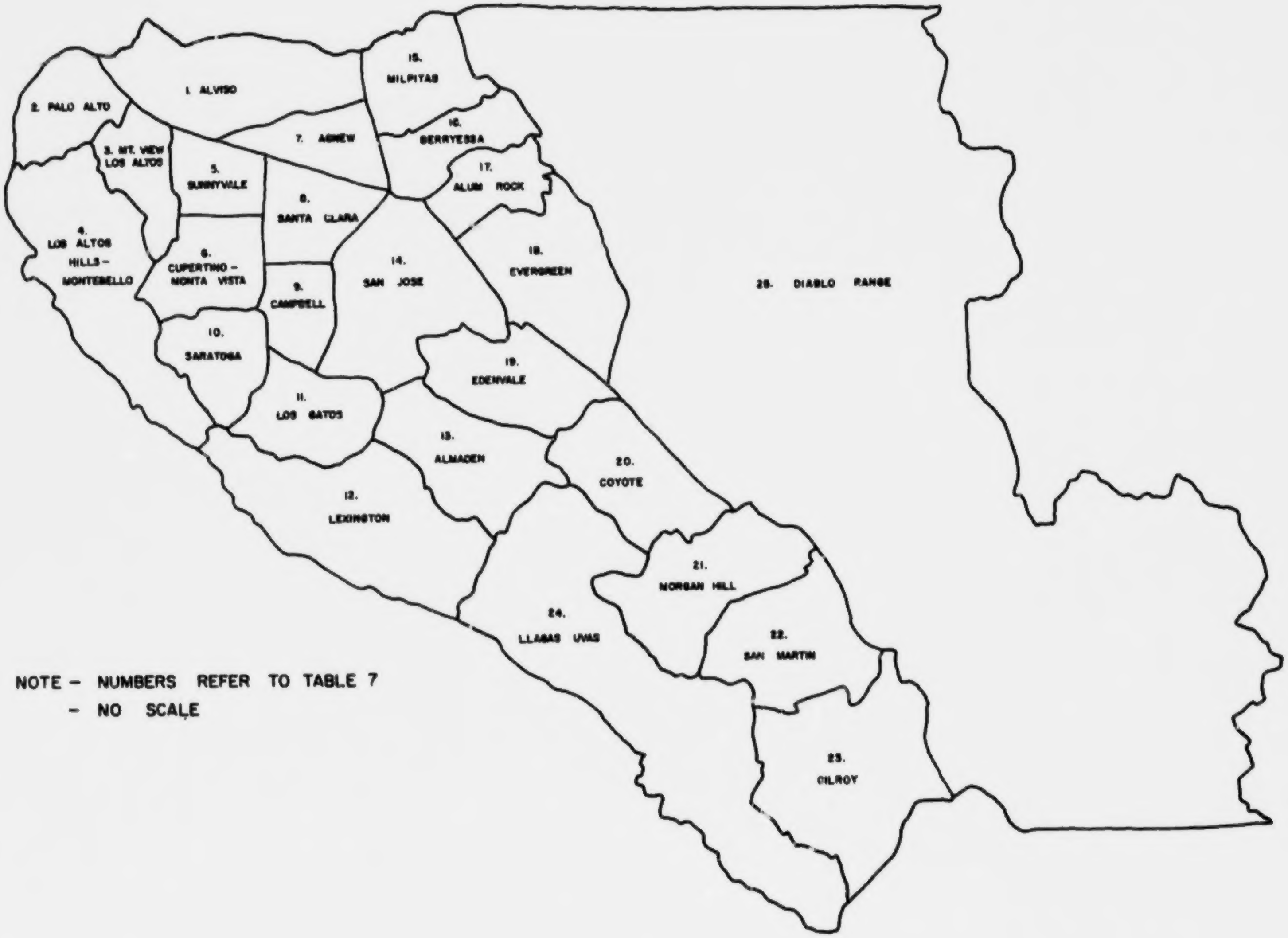
[a] On basis of solids content at 16 percent.

[b] On basis of solids content at 1200 lb/cu yd.

food processors for use in products in which chicken meat is the principal constituent. The egg layers generate about 55,100 tons (29% solids) manure/yr. The manure is rather wet and amorphous in texture. Generally, it is hauled away. However, one operator dries and sells his chicken manure, while another quite successfully disposes of his chickens' waste with the use of an anaerobic lagoon. The fryers generate approximately 12,570 tons (29% solids) of manure/yr. Waste generated in the raising of fryers differs considerably in nature from that of wastes from egg-laying operations. Fryers are raised on a sawdust litter and consequently wastes produced in the operation are relatively dry and easy to handle. Because of the improvement in texture and in overall quality brought about by the incorporation of the sawdust, the material is easily disposed of through sales to local nurserymen, by whom it is in great demand. The manure is used primarily within the country.

Carcasses: The disposal of dead animals is not a problem in the county at present, since tallow rendering plant operators will pick up the carcasses, provided they are placed in metal containers. Dead chickens constitute a large portion of the yearly collection of carcasses.

Grape and Orchard Prunings: In 1965 there were 56,731 acres of bearing and nonbearing trees and vines in Santa Clara County. Data concerned with


1. ALVISO
2. PALO ALTO
3. MT. VIEW LOS ALTOS
4. LOS ALTOS HILLS – MONTEBELLO
5. SUNNYVALE
6. CUPERTINO – MONTA VISTA
7. AGNEW
8. SANTA CLARA
9. CAMPBELL
10. SARATOGA
11. LOS GATOS
12. LEXINGTON
13. ALMADEN
14. SAN JOSE
15. MILPITAS
16. BERRYESSA
17. ALUM ROCK
18. EVERGREEN
19. EDENVALE
20. COYOTE
21. MORGAN HILL
22. SAN MARTIN
23. GILROY
24. LLAGAS UVAS
25. DIABLO RANGE

NOTE – NUMBERS REFER TO TABLE 7
– NO SCALE

FIGURE 3. PLANNING AREAS AND DISTRIBUTION DAIRIES IN SANTA CLARA COUNTY

TABLE 8

POULTRY MANURE GENERATION IN SANTA CLARA COUNTY

LAYERS AND BROODERS

Planning Area	No. Birds	Percent of Total	Wet Weight tons/yr	Dry Weight[a] tons/yr	Volume[b] cu yd/yr
6	4,500	.37	204	59	255
7	7,000	.58	320	93	400
11	13,000	1.08	595	173	743
13	8,500	.70	386	112	482
14	5,800	.48	265	77	331
16	15,000	1.24	683	193	854
17	9,000	.75	413	120	517
18	11,000	.91	501	145	627
19	5,000	.41	226	66	283
20	72,400	6.00	3,300	958	4,128
21	229,000	18.95	10,437	3,027	13,030
22	407,000	33.70	18,570	5,385	23,200
23	421,000	34.83	19,200	5,570	24,000
TOTAL	1,208,700	100.00	55,100	16,000	68,850

FRYERS

Planning Area	Avg. No.[c] Birds	Percent of Total	tons/year @ 29% T.S.	Total Solids tons/year	Volume cu yd[d]
14	45,000	16.4	2,060	598	5,150
19	45,000	16.4	2,060	598	5,150
21	160,000	58.1	7,310	2,122	18,300
22	25,000	9.1	1,140	332	2,850
TOTAL	275,000	100.0	12,570	3,650	31,450

[a] On basis of solids content at 29% of wet weight.

[b] On basis of 1500 lb/cu yd.

[c] Based on 4-1/2 generations per year.

[d] One cu yd = 800 lb.

quantities produced with type of crop are listed in Table 9. As listed in the table, the yearly production of prunings amounts to approximately 75,000 tons. Orchard prunings constitute about 91 percent of this amount.

TABLE 9

QUANTITIES OF PRUNINGS BY CROPS IN SANTA CLARA COUNTY

Crop	Bearing Land			Non-Bearing Land			
	Land (acres)	Prunings		Land		Prunings	
		tons/acre/yr	tons/yr	acres	Bearing (%)	tons/acre/yr	tons/yr
Apples	170	2.250	382	14	50	1.125	16
Apricots	7,571	2.125	16,100	261	25	0.534	140
Cherries[a]	1,915	0.4125	790	607	50	0.206	125
Grapes	3,303	2.000	6,606	66	50	1.000	66
Peaches	69	1.835	127	3	50	0.902	3
Pears	5,105	2.250	11,500	714	33-1/3	0.750	536
Plums	96	1.350	130	41	25	0.340	14
Prunes	26,408	1.150	30,450	2,361	25	0.290	686
Walnuts	7,120	1.000	7,120	381	50	0.500	191
Misc.	280	-	18	-	-	-	-
			73,223				1,777

[a] Cherries not pruned after 6th year.

Burning is the usual method of disposing of prunings. They either may be buckraked to the site for burning or may be carted there on a sled or trailer. Generally, apples, apricot, cherry, peach, and pear trees are pruned and the prunings burned in the winter. Grape vines, prune trees, and walnut trees are pruned and the trimmings burned during the late winter and spring months. This means that 90 percent of the total wastes from deciduous fruit and nut trees and from grapevines are burned during the winter months. Waste burning exercised as a means of apricot and pear tree disease control is done in June and September, since cytospore infected apricot wood should be removed during June, and fireblight infected pear wood should be eliminated by the end of September. Dead or dying trees generally are burned during January, February, and March. Burning generally has been replaced by disking as a means of disposing of grapevine prunings in modern vineyards. Burning continues to be practiced in the older vineyards in which close planting precludes a disking operation.

Shredding followed by incorporation of the shredded wastes in the soil has been tried as a means of disposing of orchard wastes in the county. Advantages of the shredding-burying system of disposal are: 1) avoidance of the air pollution which results from burning the prunings, and 2) returning organic matter to the soil. Because of the hot dry climate characteristic of the region in which orchards are situated, the shredded wastes are decomposed within a period of six months or less. However, decomposition proceeds at a much slower pace in the moist soils and cooler climate characteristic of those regions adjacent to the Bay. A grave disadvantage inherent in incorporating the shredded material into an infected soil is that the chips can provide an excellent harborage and source of nutrient for certain fungi, as for example Armillaria mellea (oak root fungus). As such, the chips would make it possible for the fungus to survive long beyond the time it would otherwise have persisted. Moreover, if the chips do not decompose sufficiently rapidly, there is the strong possibility that they may serve as a means of spreading the fungus to noninfected soils. Another hazard is the possibility that the chips may serve as a food for subterranean termites. The persistence of these termites is a problem in the older apricot and prune orchards in the Bay area.

Until means are found for controlling the survival of plant pathogens in the buried plant wastes, burning will continue to be the only safe way (with respect to plants) of disposing of orchard and vineyard residues. Research concerned with finding these means is now under way at the University of California at Riverside. Disinfection by chemicals would seem to be one way of circumventing the spread of the fungal diseases. Unfortunately, chemical control is not presently feasible with respect to pests which bore into branches or twigs. Among such organisms are the shot-hold borer, the branch and twig borer, and the cane maggot. The overall problem of disposal is further complicated by the refusal of the San Francisco Bay Area Air Pollution Control District to allow burning of agricultural debris beyond the next two-year period.

Greenhouse Wastes and Harvesting Residues: At present greenhouse wastes are hauled to sanitary landfills for disposal. Although not constituting a refuse disposal problem per se, residues left in fields and orchards do give rise to problems with respect to vector breeding and to aesthetics.

Pesticide Containers: Accumulations of pesticide containers were observed in several locations. Such a practice is fundamentally unsatisfactory, especially where, because of the pesticide residue remaining in them, the accumulated containers may constitute a hazard to children, pets, and livestock, or to adults who may attempt to put the containers to other uses. Unfortunately, the containers in which pesticides are distributed are especially attractive for such uses. Combustible containers should be burned directly after having been emptied; and noncombustible containers should be treated along with other noncombustible refuse.

From the study of Agricultural Wastes in Santa Clara County it is concluded that, because of the nature and quantity of the wastes generated, the disposal problem of agricultural wastes is as acute as that of municipal wastes. While the problem in Santa Clara County is intensified because of the large quantity of agricultural wastes generated per capita, along with the ban placed on burning by the Bay Area Air Pollution Board, the situation underscores a need for agricultural wastes to be considered in any community-wide plan of solid wastes management.

Special Wastes: Included under the heading "Special Wastes" are all wastes not covered in the categories domestic, industrial, and agricultural. Included in this broad category are wastes ranging from street sweepings and demolition debris to sewage sludge. At present, quantitative data on the wastes falling into the 'special' category are either nonexistent or are too fragmentary to be of use.

Change in the Composition of Berkeley Wastes

Introduction. The second field investigation of the composition of refuse made during Phase I of the study was an intensive short-term analysis of municipal refuse of the City of Berkeley, California. Several considerations made such an analysis desirable and suggested Berkeley as the appropriate place to undertake it.

First is the necessity, as pointed out in the Santa Clara County study, of using values reported from widely scattered sources in the past in estimating the waste generating potential of the domestic sector of a specific community today. Second is the current belief that the characteristics as well as the per capita production of wastes have changed with the years. This belief is easily substantiated rationally by the general knowledge of changes in the packaging industry — the development of "TV" dinners, the multiplication of uses for plastics, the non-returnable bottle, and similar innovations. It is not, however, easily documented, particularly as to its effects on estimates of refuse production based on the analytical data which have been produced in the past. Even in a single specific community for which data are available, predictions based on the passage of time must always assume that conditions remain similar to those under which the basic observations were made, subject only to modifications to compensate for increased per capita output and shifts in the nature of the area affected (e.g., from residential to commercial, etc.). The underlying rationale of the study herein reported, however, is that the foregoing assumption must be seriously questioned and that a knowledge of the effect of time on change in composition of refuse is essential in predicting waste generation, and hence in designing waste management systems.

The selection of Berkeley as a place to spot check changes in the composition of municipal refuse with time was a result of more than simple geographical convenience. Because of the dearth of information on work done prior to the past few years, studies concerned with the effect of time, at least extended periods of time, are generally not feasible except in isolated cases. Berkeley is just such a case. In June of 1952, as a part of a project concerned with the reclamation of municipal refuse by composting, the Sanitary Engineering Research Laboratory analyzed incoming domestic and light commercial refuse from selected areas of the City of Berkeley. This was classified as to chemical and physical composition and origin over a period of one month [2]. With this information at hand it seemed probable that a repetition of the analysis might yield important evidence of the changes in composition and amount of refuse over the years. Therefore, in May 1967 the 1952 survey was repeated under closely similar conditions. Refuse was again collected from the same areas and was classified as in the 1952 study.

Equipment and Procedure. Facilities for conducting the study consisted of a 15-in. wide by 27-ft long conveyor belt, suitable containers (44-gal "toters"), a scale, rake, and pitch forks. A picture of the setup is shown in Figure 4. The procedure was relatively simple. Each day a truckload of refuse collected on a route identical with that followed in 1952 was dumped into a chute leading to a conveyor belt. (The truckload of refuse was weighed on a public weighing scale prior to coming to the dump.) The compacted refuse was loosened by means of the rake and pitch forks and then gradually fed to the conveyor belt. Here the items were handpicked, classified, and then deposited in nearby containers. As each container was filled its contents was weighed and recorded, as is shown in Figure 5.

It requires two loads to handle the daily route of each City of Berkeley collection crew. During the segregation study, only the first load collected in each route was processed. However, since the area served by each route is relatively uniform throughout with respect to economic level and class of dwellings, no substantial difference should exist between the compositions of the first and second loads. The weights of the various loads from the various routes and the percentages of the total refuse that was segregated in the study are given in Table 10. According to the table, about 30 tons of refuse was segregated, or about 60 percent of the total refuse collected in the areas.

An idea of the types of accounts served by the various routes may be gained by consulting the data in Table 11, in which is given a breakdown of the various dwellings receiving service. The principal change in type of dwelling over the

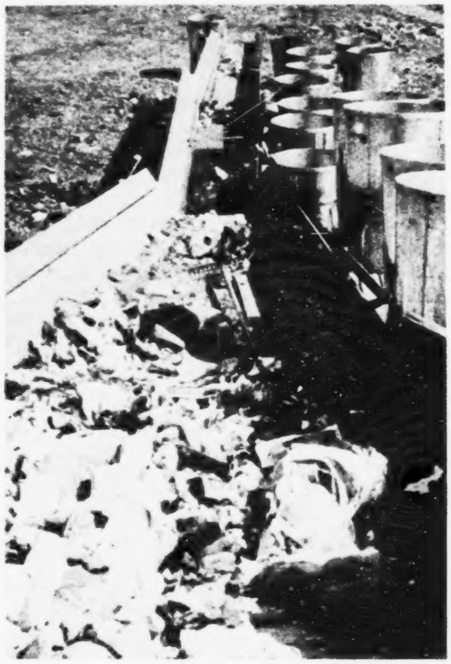


FIGURE 4. SETUP FOR SEGREGATING REFUSE AT THE BERKELEY WASTE DISPOSAL SITE

past 15 years was the reduction in number of homes and increase in number of apartment houses.

Results. The weights of the various components of the refuse are listed in Table 12, and their percentages in Table 13. The changes in respective weights of the components which took place over the 15-year period between 1952 and 1967 is indicated by the data listed in Table 14; and that in percentage composition, in Table 15.

The material listed under "Garbage and Garden Debris" was, with respect to weight, about 80 percent in the form of garbage. The reverse was true in terms of volume, since the garden debris was much bulkier than the garbage. In general, the garbage fraction of the garbage-garden debris mixture was higher in the low income neighborhoods than in the high income districts. Large items of garbage were mostly in the form of bones and wastes too large or unsuited to disposal in the home garbage grinder. Items classified as shoes included rubbers, plastic rain-shoes, "thongs" (zories), and tennis shoes, as well as the leather varieties. Interestingly, in 1952 shoes of the leather variety constituted the greater part of the items in this category; whereas in 1967 they were only a small fraction of the total. Most of the glass waste was in the form of bottles or jars, as is shown in Figure 6. It is interesting to note that there were more and better grade liquor bottles from the medium and high level income areas than from the low income areas. The reverse was true with respect to beer cans.

The compostable material listed in Table 14 and 15 includes paper and other material which could be amenable to composting. The heading is not intended to convey the impression that the material would be suited to composting as it is, i.e., as having the proper C:N ratio for good composting. For example, the wastes from the light-commercial district, although compostable, could not be composted without the addition of nitrogen. The garbage and garden debris were grouped with soiled paper under "compostable" refuse in the 1952 studies. However,

FIGURE 5. WEIGHING SEGREGATED REFUSE ITEMS

TABLE 10

WEIGHT OF THE INDIVIDUAL LOADS OF REFUSE AND THE PERCENTAGE OF TOTAL REFUSE PER ROUTE THAT WAS SEGREGATED

Route	Type of District[a]	Weight (lb)			Percentage Segregated
		1st Load	2nd Load	Total	
H-2	Low-Med. Residential	9,210	6,900	16,110	56
West Special	Low Residential	8,940	5,130	14,070	64
L-4	Low Residential	10,270	5,940	16,210	63
O-1	Low-Med. Residential	7,590	7,530	15,120	50
A-2	Med. - High Residential	8,720	6,390	15,110	58
R-3	Apts. and Light Commercial	6,210	1,680	7,890	79
C-4	Med. - High Apt. Residential	8,420	5,940	14,360	59
Total		59,360	39,510	98,870	60

[a] Income level.

TABLE 11

TYPE OF ACCOUNT RECEIVING REFUSE SERVICE

Route	Income Level	Residences	Apartment Houses	Stores	Total
H-2	Low to Med.	407	37	5	449
West Special	Low	272	21	24	317
L-4	Low	353	23	14	390
O-1	Low to Med.	345	22	15	382
A-2	Med. to High	423	-	-	423
R-3	Med. to High	-	28	72	100
C-4	Med. to High	310	64	2	376

TABLE 12

COMPOSITION OF BERKELEY REFUSE IN TERMS OF WEIGHT[a]

Route	Day of Week	District[b]	Load	Paper		Garbage[e] & Garden Debris	Bottles, Broken Glass	Tin Cans	Plastics	Rags	Metal	Shoes	Misc.[f]
				Soiled[c]	Clean[d]								
H-2	Tues.	Low - Med. Resid.	9,210	3,005	813	1,783	1,277	913	257	153	29	38	942
West Special	Wed.	Low Resid.	8,940	3,139	342	2,402	1,037	958	159	103	18	41	741
L-4	Thurs.	Low Resid.	10,270	4,140	278	2,769	1,036	864	194	176	44	52	717
O-1	Mon.	Low - Med. Resid.	7,590	2,852	143	2,281	869	669	151	32	15	9	569
A-2	Tues.	Med. - High Resid.	8,720	3,219	306	2,620	1,157	625	163	82	41	25	482
R-3	Wed.	Apts. Light Comm.	6,210	1,578	2,661	955	355	206	72	17	26	Tr.	340
C-4	Thurs.	Med. - High Apt. Resid.	8,420	2,670	1,335	2,077	996	722	101	69	15	12	423
Total			59,360	20,603	5,878	14,887	6,727	4,957	1,097	632	188	177	4,214

[a] Expressed as pounds.

[b] Based on income level and type of dwelling.

[c] Paper which had been in contact with garbage; no market as salvage.

[d] Paper which would have a market value.

[e] At least 80% garbage.

[f] Dirt, rocks, wood, etc.

TABLE 13

COMPOSITION OF BERKELEY REFUSE IN TERMS OF PERCENTAGES

Route	Day of Week	District[a]	Paper		Garbage[d] & Garden Debris	Bottles, Broken Glass	Tin Cans	Plastics	Rags	Shoes	Metal	Misc.[e]
			Soiled[b]	Clean[c]								
H-2	Tues.	Low - Med. Resid.	32.6	8.8	19.4	13.9	9.9	2.8	1.7	0.4	0.3	10.2
West Special	Wed.	Low Resid.	35.1	3.8	26.9	11.6	10.7	1.8	1.2	0.5	0.2	8.3
L-4	Thurs.	Low Resid.	40.3	2.7	30.0	10.1	8.4	1.9	1.7	0.5	0.4	7.0
O-1	Mon.	Low - Med. Resid.	37.6	1.9	30.1	11.5	8.8	2.0	0.4	0.1	0.2	7.5
A-2	Tues.	Med. - High Resid.	36.9	3.5	30.1	13.3	7.2	1.9	0.9	0.3	0.5	5.5
R-3	Wed.	Apts. Light Comm.	25.4	42.9	15.4	5.7	3.3	1.2	0.3	Tr.	0.4	5.5
C-4	Thurs.	Med. - High Apt. Resid.	31.7	15.9	24.7	11.8	8.6	1.2	0.8	0.1	0.2	5.0
Average 7 Loads			34.7	9.9	25.1	11.3	8.4	1.9	1.1	0.3	0.3	7.1

[a] Based on income level and type of dwelling.

[b] Paper which had been in contact with garbage; not marketable.

[c] Paper having a market value.

[d] At least 80% garbage.

[e] Dirt, rocks, wood, etc.

TABLE 14

COMPARISON OF THE COMPOSITION OF REFUSE IN 1967 WITH THAT IN 1952 IN TERMS OF WEIGHT[a]

Route	Year	Load	Tin Cans	Bottles, Broken Glass	Rags	Metals	Shoes	Plastics[b]	Compostable[c] Material	Wastes of[d] No Value
H-2	1967	9,210	913	1,277	153	29	38	257	5,601	942
	1952	6,400	703	689	103	49	32	Tr.	4,343	481
West Spec.	1967	8,940	958	1,037	103	18	41	159	5,883	741
	1952	6,200	499	614	164	63	25	Tr.	4,350	485
L-4	1967	10,270	864	1,036	176	44	52	194	7,187	717
	1952	7,240	903	977	49	35	22	Tr.	4,826	428
O-1	1967	7,590	669	869	32	15	9	151	5,276	569
	1952	6,100	668	842	93	Tr.	Tr.	Tr.	4,047	450
A-2	1967	8,720	625	1,157	82	41	25	163	6,145	482
	1952	6,760	706	740	111	Tr.	Tr.	Tr.	4,683	520
R-3	1967	6,210	206	355	17	26	Tr.	72	5,194	340
	1952	5,080	355	357	55	100	Tr.	Tr.	3,792	421
C-4	1967	8,420	722	996	69	15	12	101	6,082	423
	1952	4,240	354	550	65	Tr.	Tr.	Tr.	2,944	327
Total (7 Loads)	1967	59,360	4,957	6,727	632	188	177	1,097	41,368	4,212
	1952	42,020	4,188	4,769	640	247	79	Tr.	28,985	

[a] Weight in pounds.

[b] Plastics were not measured in 1952 because they were insignificant as a refuse component at that time.

[c] The 1967 figures include soiled paper, clean paper, garbage, and garden debris.

[d] Wastes which can be used neither for compost nor as a marketable salvage.

TABLE 15

CHANGES IN COMPOSITION OF REFUSE OVER 15-YEAR PERIOD[a]

Route	Year	Type of[b] District	Tin Cans	Bottles, Broken Glass	Rags	Metals	Shoes	Plastics[c]	Compostable[d] Material	Wastes of[e] No Value
H-2	1967	Low - Med.	9.9	13.9	1.7	0.3	0.41	2.8	60.8	10.2
	1952	Resid.	11.0	10.8	1.6	0.8	0.50	Tr.	67.8	7.5
West Spec.	1967	Low	10.7	11.6	1.2	0.2	0.46	1.8	65.8	8.3
	1952	Resid.	8.0	10.0	2.6	1.0	0.04	Tr.	70.2	8.2
L-4	1967	Low	8.4	10.1	1.7	0.4	0.51	1.9	70.0	7.0
	1952	Resid.	12.5	13.5	0.7	0.5	0.03	Tr.	66.6	6.2
O-1	1967	Low - Med.	8.8	11.5	0.4	0.2	0.12	2.0	69.5	7.5
	1952	Resid.	11.0	13.8	1.5	Tr.	Tr.	Tr.	66.3	7.4
A-2	1967	Med. - High	7.2	13.3	0.9	0.5	0.28	1.9	70.5	5.5
	1952	Resid.	10.4	10.9	1.6	Tr.	Tr.	Tr.	69.4	7.7
R-3	1967	Apts.	3.3	5.7	0.3	0.4	Tr.	1.2	83.6	5.5
	1952	Light Comm.	7.0	7.0	1.0	2.0	Tr.	Tr.	74.7	8.3
C-4	1967	Med. - High	8.6	11.8	0.8	0.2	0.14	1.2	72.2	5.0
	1952	Apt. Resid.	8.4	13.0	1.5	Tr.	Tr.	Tr.	69.4	7.7
Average (7 Loads)	1967		8.4	11.3	1.1	0.3	0.3	1.9	69.7	7.1
	1952		10.0	11.4	1.5	0.6	0.2	Tr.	69.0	7.4

[a] Values are those for percentage of total load.

[b] Based on income level and type of dwelling.

[c] Plastic content of 1952 refuse was practically nonexistent.

[d] 1967 - report on compost figures includes soiled paper, clean paper, and garden debris.

[e] Wastes usable neither for compost nor as a marketable salvage.

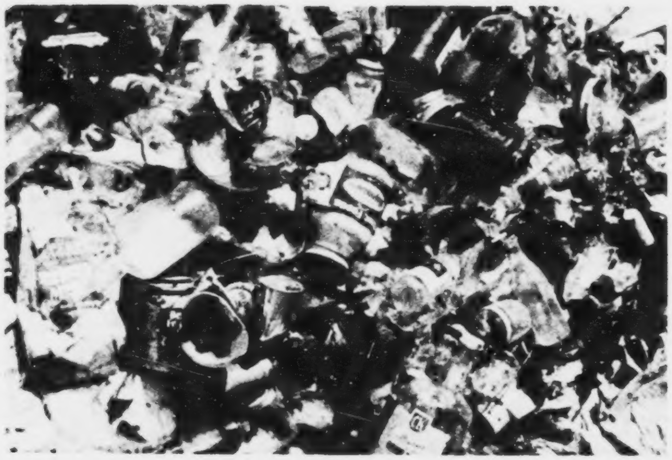


FIGURE 6. TYPICAL GLASS WASTE SEGREGATED IN BERKELEY STUDY

judging from observations made in the 1952 and 1967 studies, the garbage fraction in the 1952 studies was about twice that of the 1967 study.

Discussion. In interpreting the data in Tables 12 and 13, it should be noted that they concern paper which had been stuffed into a common container, had been compacted, and had been dumped in one big pile — all with other refuse. Hence, opportunities for the paper to become soiled by contact with garbage were more than ample. Obviously if the paper had been segregated at the source, the ratio of soiled to clean paper, as found in the present study, might well have been reversed. Most of the paper, soiled and clean, was in the form of newspapers. When garbage was encountered it usually was contained in a paper bag.

The weights of the plastics and of the garbage-garden debris are not indicative of their relative volumes in the total refuse volume. Plastic is extremely light in weight, especially since most of it was in the form of film or wrappers, as is shown in Figure 7. On the other hand, garbage and garden debris, because of their high moisture content, are quite dense. Using tin cans as a comparison (shown in Figure 8), a filled container of the type used in the studies would contain from 60 to 90 lb of tin cans, from 10 to 20 lb of plastics, or from 150 to 200 lb of garbage.

A comparison between the 1952 and 1967 studies indicates that the load weights increased materially, as is shown by the total weights of 7 loads in 1952 and 1967 — the total weight of 7 loads was approximately 40 percent greater in 1967 than in 1952. Since in both studies the first load of the day was the one being studied, no doubt exists as to fact that the trucks were loaded to capacity in each study. (A common complaint among dump operators is about the tendency of the collection crews to pack the first load of the day.)

In the fifteen-year interim, the percentages of tin cans, bottles and broken glass, rags, metal, shoes, and the wastes of "no salvage value" changed very little.

As stated earlier, the garbage fraction of the 1967 refuse was only about 50 percent that of the 1952 refuse. The decrease in the garbage fraction is due, as is true throughout the U. S. to:

FIGURE 7. TYPICAL PLASTICS SEGREGATED FROM DOMESTIC REFUSE

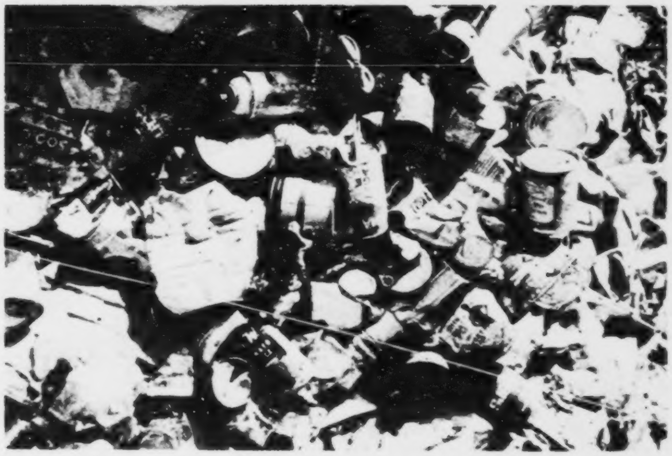


FIGURE 8. TIN CANS SEGREGATED FROM DOMESTIC REFUSE

1. Increase in the number of homes equipped with garbage disposal units in the medium and high income areas;

2. Increase in frozen food consumption; and

3. Increase in the comsumption of "TV" dinners.

The increase in the frozen food consumption was accompanied by an increase in the generation of soiled paper. According to this small study, the increase in the consumption of "TV" dinners was especially pronounced in the low income areas — as judged by the number of empty "TV" dinner containers in their refuse.

Undoubtedly the compostable fraction of the 1967 refuse would be less desirable than that of the 1952 refuse for a compost operation. The former had a much larger fraction of paper and garden debris than did the latter. For example, meat scraps and green vegetable trimmings were far more abundant in the 1952 refuse, whereas they were almost nonexistent in the 1967 refuse. As stated before, the 1967 compostable material would have to be fortified with nitrogen in any practical composting operation; whereas in 1952 only the light commercial refuse had a suboptimum C:N ratio (i.e., excessively high C:N ratio).

An interesting sidelight on the change in living standards or habits is given by the change in the nature of the items constituting the "shoe" category. As noted in a preceding paragraph, discarded shoes in 1952 were mostly of the leather variety, and more shoes than shoe substitutes and rain gear were discarded. In 1967, however, the leather variety of shoe was far less abundant than the substitute, i.e., zories (thongs) and tennis shoes. More rain gear (plastic rainguards for women's shoes) also were noted in 1967. Reasons for the changes are that Japan had not begun exporting the zori, and plastic "booties" had not been produced to any great extent in 1952. Probably the greater part of the leather variety of shoes ends up in Goodwill or Salvation Army collection centers.

Except for the items listed under "rags" and "shoes", and of course other than those in the apartment-light commercial district, in 1967 no significant difference was observed between neighborhoods (i.e., low, medium, and high income districts) with respect to percentage composition of the refuse collected in each of them. Interestingly, the amount of rags in the refuse from the low income districts averaged 70 percent more than that from the medium-high and 39 percent more than that from the low-medium income neighborhoods. The differences were even more pronounced with respect to shoes, with the low income neighborhoods discarding more than three times the amount of "shoes" as did the medium-high income neighborhoods, and twice that from the low-medium income neighborhoods. In 1952 rag production was about the same in all districts. It is difficult to state what the case was with respect to "shoes" in 1952, since the amount of the discard was so small that it was recorded as a trace amount and no actual weights are at hand. The higher production of the rags in the low income districts probably is due to the fact that items that have outlived their usefulness to their owners in the low income bracket have no direct reuse potential, and hence end in the refuse can. On the other hand, cloth items (clothing) discarded in the medium and high income neighborhoods can be used again, and hence ends either in a "Used Clothing" store or at Goodwill Industries or the Salvation Army.

No estimates are given at this time regarding change in per capita production of refuse. Such estimates would require some searching of the City of Berkeley's records with respect to population or census tracts. The time interval between the computation of the observations at the dump and the writing of this report was not long enough for such a search. However, it will be made during the coming year, and further appropriate analyses will be made at that time.

Definition and Coordination of Research Areas

The fifth and final aspect of Phase I of the study was that of defining and coordinating the areas of research to be undertaken by the separate research teams during Phase II of the study. Initially, of course, certain decisions had to be made regarding Phase II in order to constitute the overall investigative group which was to participate in Phase I. Thus it was known from the beginning of the project that planning, operations research, public health, and technology would all be given special attention. Furthermore, it was expected that coordination of the ongoing research would be maintained by the participating faculty, as outlined in Part I. During the course of Phase I, however, it became clear that economics should be given greater attention by the planning and operations research teams and that salvage, biological oxidation, and wet oxidation studies should be added to the planned studies of technology of landfill, incineration, and composting.

The most important feature of the final aspect of Phase I, however, was the development of a Regional Waste Generation and Evaluation Model into which the entire project activity could be fitted in such a manner that the product of each research team was coordinated with that of every other team toward a common goal. This model is presented in Figure 9 and explained in some detail in the following chapter.

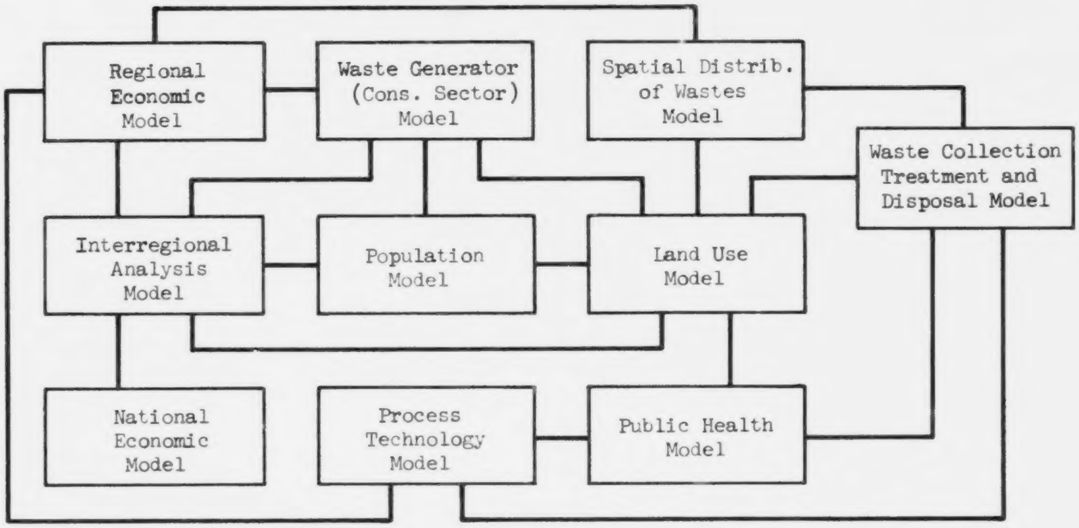

Regional Economic Model
Waste Generator (Cons. Sector) Model
Spatial Distrib. of Wastes Model
Waste Collection Treatment and Disposal Model
Interregional Analysis Model
Population Model
Land Use Model
National Economic Model
Process Technology Model
Public Health Model

FIGURE 9. REGIONAL WASTE GENERATION AND EVALUATION MODEL

From the figure it is evident that the model designed to describe waste collection, treatment, and disposal for an individual region or community depends upon inputs and feedbacks from a number of other models or subsystems. The activities of each of the several research teams are associated with one or more of the subsystems. The place of public health and of technology in the overall model is clearly shown in Figure 9. The planning team is simultaneously concerned with land use, population, spacial distribution, and economic models. Operations research is concerned with the whole system and with the economics, transportation, and analytical aspects. (See Chapter III.) Operations research likewise serves to maintain the framework and to develop further the subsystems on which success of the overall waste generation evaluation model depends.

With the development of the model and its subsystems the study was prepared to proceed with Phase II, although various aspects of Phase I must continue indefinitely. Specifically the collection and evaluation of data maintenance of retrieval system, and compiling of information on components of refuse are all continuous activities which form a part of several of the subsystems depicted in Figure 9.

PART III
PHASE II. DEFINITIVE RESEARCH

III. OPERATIONS RESEARCH

INTRODUCTION

Investigative work of the operations research team proceeded from the basic concept that the need for engineering and technological advances in the treatment, disposal, and recovery of solid wastes is subordinate only to the need for effective management and operation of such systems. Furthermore, the systems are themselves so complex and large in scale that tenable plans and decisions concerning their future nature and operation may be considerably enhanced by the application of 'systems analysis' types of studies [39,40]. Such studies lend themselves to broad interdisciplinary approaches such as might be required for the solid wastes problem, in which such diverse factors as economics, public health, engineering, law, sociology, political science. city planning, geography, and demography need to be considered. Examining the effect of such factors on some meaningful measure of worth in order to obtain an optional plan of decisions and operations is the traditional domain of operations research. Recognizing, of course, that optimizing a system in which some of the inputs are qualitative while other are quantitative in nature is no simple routine task, the study herein reported is nevertheless based on the concept that effective management of solid wastes in a community involves the type of complex interrelationships to which systems analysis methods are well suited.

The broad objective of the study was to explore the potential of operations research to help in the definition and solution of the solid waste disposal problem. Initially the task was to develop an overall conceptual model which would integrate the research efforts of all research teams in the four definitive research areas, and which would provide the framework for evaluating alternative solutions to the total refuse disposal problem. The expectation was that the model would be flexible enough to be applicable to a wide spectrum of alternatives such as, for example, ocean disposal and use of transfer stations, mobile treatment units, stationary processing plants, or home disposal units; it would be sensitive to environmental constraints and governmental controls; and useful in determining location of intermediate and final master transfer points, collection routes, etc.

The second task implicit in the general objective of the research was to convert the conceptual model into a mathematical model by which the inputs from the various research teams in the several areas of definitive research could be utilized to develop the optimum decisions and operational procedures on which management depends. It was envisioned that this overall mathematical model would probably make use of digital computational techniques, and be programmed and coordinated by a systems analysis team under the primary responsibility of the operations research and planning and economics research teams.

The first of the two tasks was completed during Phase I of the study. The results are summarized in Figure 9. Progress in the development of the mathematical model is the subject of the remainder of this section of the report.

WASTE GENERATION AND EVALUATION MODEL

The overall or regional waste generation model depicted in Figure 1 (page 8) consists of several elements or subsystems which are in themselves complex in nature. However, before a waste system can be evaluated it is necessary to know something of its properties and interrelationships with outside factors, the physical nature of the system, and how to estimate its inputs. In the case of solid wastes management the most important prime mover of the system is the input waste load. For this reason, it was decided to develop some method of predicting the waste profile for an arbitrary region and time period. The result of such a development is the mathematical model of wastes generation presented in Figure 10 and the related Table 16 which defines the symbols used.

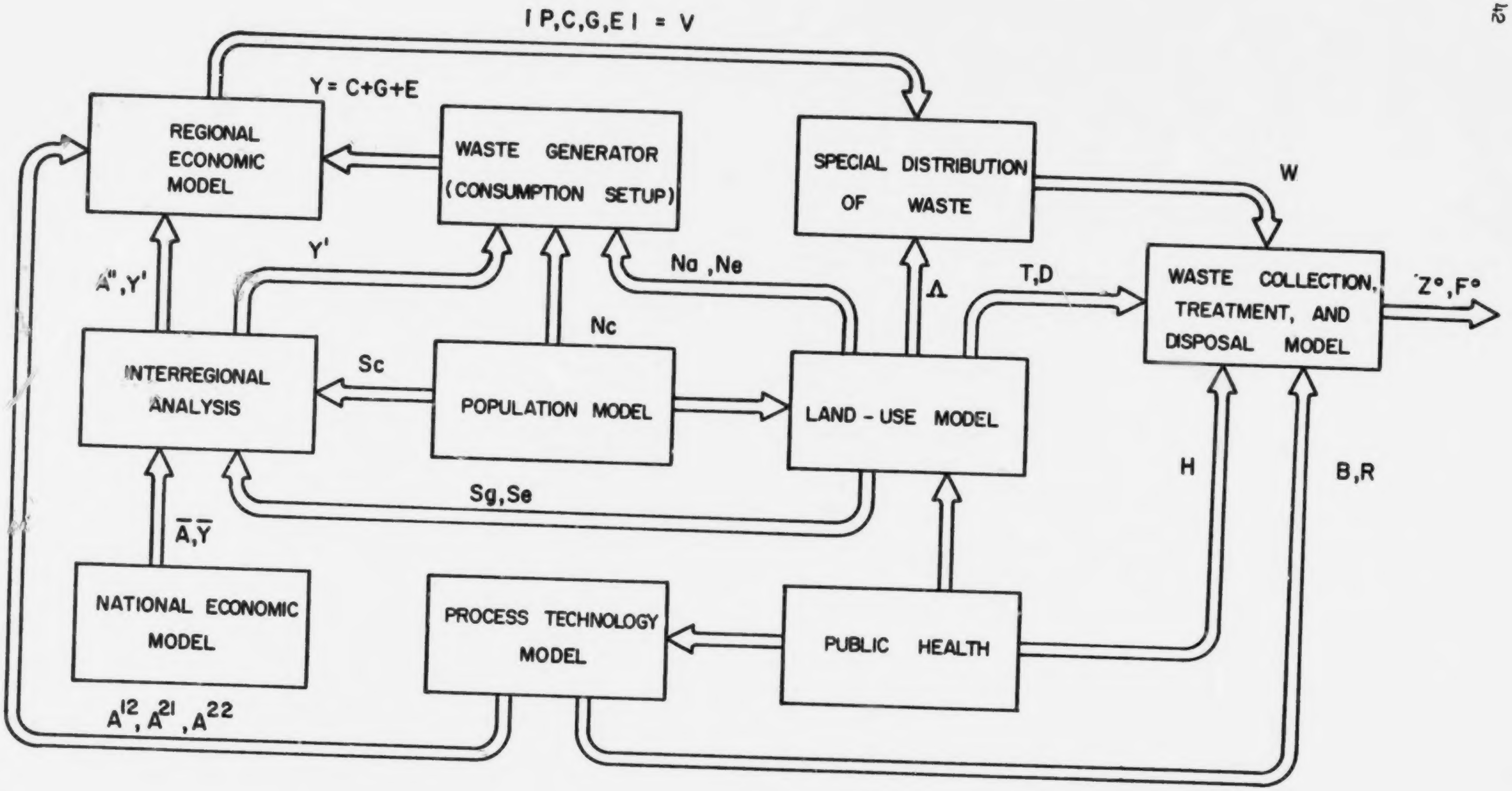

I P,C,G,E I = V
Y = C+G+E
REGIONAL ECONOMIC MODEL
WASTE GENERATOR (CONSUMPTION SETUP)
SPECIAL DISTRIBUTION OF WASTE
W
WASTE COLLECTION, TREATMENT, AND DISPOSAL MODEL
Z°, F°
A'', Y'
Y'
Na , Ne
Nc
Λ
T,D
INTERREGIONAL ANALYSIS
Sc
POPULATION MODEL
LAND - USE MODEL
H
B,R
Sg, Se
A̅, Y̅
NATIONAL ECONOMIC MODEL
PROCESS TECHNOLOGY MODEL
PUBLIC HEALTH
A12, A21, A22

FIGURE 10. MATHEMATICAL MODEL OF WASTE GENERATION

TABLE 16

INFORMATION FLOW FOR REGIONAL WASTE GENERATION AND EVALUATION MODEL

Symbol	Definition
$\overline{A}$	The n x n national technological coefficient matrix with general element $\{a_{ij}\}$ representing the value of goods or services of type i in millions of dollars required for the production of one million dollars of goods or services of type j.
$\overline{Y}$	The n x 1 yearly final demand vector for the nation.
Sc	Population figures of the two regions under consideration in terms of their consumption characteristics.
Se	The imports and exports of the n basic commodities between the two regions.
Sg	The proportion of the government consumption sector in each of the two regions.
A^{11}	Same as $\overline{A}$ but for the region under consideration.
Y^1	Same as $\overline{Y}$ but for the region under consideration.
A^{12}	An n x m matrix whose general element $\{a_{ij}\}$ represents the value of commodity i in millions of dollars required by the waste disposal activity to dispose of one ton of waste of type j.
A^{22}	An m x m matrix whose general element $\{a_{ij}\}$ represents the number of tons of type i waste disposal service required per ton of operation of waste disposal service industry j.
A^{21}	An m x n matrix whose general element $\{a_{ij}\}$ represents the number of tons of type i waste disposal service required per one million dollars worth of production by industry j.
C	An m x v matrix whose general element $\{c_{ij}\}$ represents the annual number of tons of waste of type i generated by all households in household category j.
G	An m x q matrix whose general element $\{g_{ij}\}$ represents the annual number of tons of waste of type i generated by all government units in government category j.
E	An m x r matrix whose general element $\{e_{ij}\}$ represents the annual number of tons of waste of type i generated outside of the region by import category j for disposal within the region.
Nc	Demographic data required for household categories used in waste regression analysis.
Ng	Data on number and type of government categories which produce waste to be used in waste regression analysis.
Ne	Data on waste generated outside of the region under consideration and accepted for disposal by the waste industries inside the region.
P	An m x m + n matrix whose general element $\{p_{ij}\}$ represents the annual number of tons of waste of type i generated by industrial category j.
V	An m x s [where s = m + n + v + g + r] matrix whose general element $\{v_{ij}\}$ represents the annual number of tons of waste of type i generated by all sources of category j.
Λ	An s x k matrix whose general element $\{\lambda_{ij}\}$ represents the proportion of sources of category i located in area j.
W	An m x k matrix whose general element $\{w_{ij}\}$ represents the annual number of tons of waste of type i generated at location j.
T	The node-arc incidence matrix of the transportation network of the regional waste collection and disposal model.
D	The set of disposal site waste capacities.
H	The set of Public Health constraint functions.
B	The set of coefficients representing the material balance equations of the waste interchange (treatment) stations.
R	The cost row vector representing the collection, treatment, and disposal costs of each arc in the collection, treatment, and disposal network.
Z^o	The minimum yearly cost of collecting, treating, and disposing of set of wastes W.
F^o	The allocation of waste flows and corresponding collection routes resulting from the solution of Z^o.

Three basic steps are involved in the construction of the general model (Figure 10):

1. Establish the general structure of the waste collection-treatment-disposal system.

2. Estimate its inputs for the location and time under consideration.

3. Perform an optimization study of the system and establish its feasibility and measure of worth.

These steps are indicated in Figure 10 in terms of the information flow required for the analysis.

The Waste Collection-Treatment-Disposal Model is the central core of the analysis. It describes the system in terms of a set of mathematical equations, called the constraints of the system, which include the transportation network (T), the process technology (B), public health constraint (H), five disposal capacities (D), and the initial location and magnitude of the waste sources (W). These constraints are obtained from the various sub-studies indicated on the flow chart. The Operations Research team proposes to predict (W) through the use of a number of sub-studies and models. The basic data required for this waste generator are obtained from a National Economic Model, a Population Model, and various studies from the Process Technology, Land-Use Models.

The third step, which is the determination of some measure of worth in terms of an economic objective function, may be initiated upon completion of the first two steps. Data for this mathematical function may be obtained from Process Technology in terms of cost coefficients (R). The objective function is then optimized subject to the constraint equations and produces the optimal collection plan F^o and/or measure of worth Z^o. A more detailed description of these steps in terms of the nature of each sub-block in Figure 1 appears in the sections which follow.

WASTE COLLECTION-TREATMENT-DISPOSAL MODEL

General Description

In many megalopolis areas today, solid waste collection and disposal systems are rapidly approaching environmental or economic limits. Herein lies the charter for seeking innovative and alternative methods of carrying out large-scale waste collection, treatment, disposal, and recovery operations. Initially, a single-period (one year) mathematical model is formulated to deal with the broad problem of handling total waste flows from generation points through intermediate treatment and/or transfer locations to final recovery or disposal areas. A fixed technology is assumed throughout this static analysis. The objective of this evaluation model is to ascertain the optimal operating characteristics for a single period given the cost and waste generation profiles (in magnitude, types of waste and space). Part of the optimal solution will be given in terms of location, capacity, and type of waste handling activities. In addition, the optimal allocation of waste flows between waste activities will be found. The optimization criterion will be to minimize the operating costs plus amortized investments subject to city planning, public health, and political-legal constraints.

The model is designed for regional (megalopolis size) areas although it may be utilized for single towns or rural areas as well. However, the waste problem of small communities and rural areas may be solved by a much simplier analysis. The regional model described at this time is presented in general form so as to be applicable to any specific urban waste handling and environmental control system. It must be stressed at the outset, however, that the interrelationships between conversion of types of wastes in solid, liquid, and gaseous forms play an important role in the analysis of alternative technologies and waste management systems.

It is not the intention here to develop new engineering technologies, as such, but only to evaluate the effect of their incorporation into a general waste flow management system.

By a waste flow management system, is meant the handling and conversion operations of various types of waste flow from its generation to its final absorption into the physical environment or economy. Of course, the system over time is a closed loop but initially the static analysis considers the generation and disposal activities as being independent. The interactions over time between the regeneration and reabsorption of waste flows will be considered in the dynamic Leontief Model and the multiperiod analysis of the next phase of the study. Indispensible building blocks for the multiperiod situations, however, are the single-period optimal plans hereinafter developed.

Mathematical Formulation

The essential structure of the waste collection treatment and disposal model is that of a minimum cost flow multicommodity network. The network (Figure 11) is represented by the node-arc incidence matrix T composed of rows with index set N and columns with index set A. Each row represents an interchange point, which may be divided into three sub-node sets [S, I, E,] where

$$N = [S, I, E],$$

and S = The set of source nodes representing the waste generation locations of different types of waste.

I = The set of intermediate points. These may represent treatment plants or transfer stations.

E = The set of sink nodes.

Treatment plants may be of two types, viz., those which primarily accept liquid sewage flows and convert them to solid sludge for final disposal or recovery, and those which primarily accept solid waste input flows and convert them to solid and liquid resultant flows in addition to salvage material through the operations of grinding and sorting. Transfer stations are points where solid wastes are stored and/or transferred to different haul vehicles for further transport.

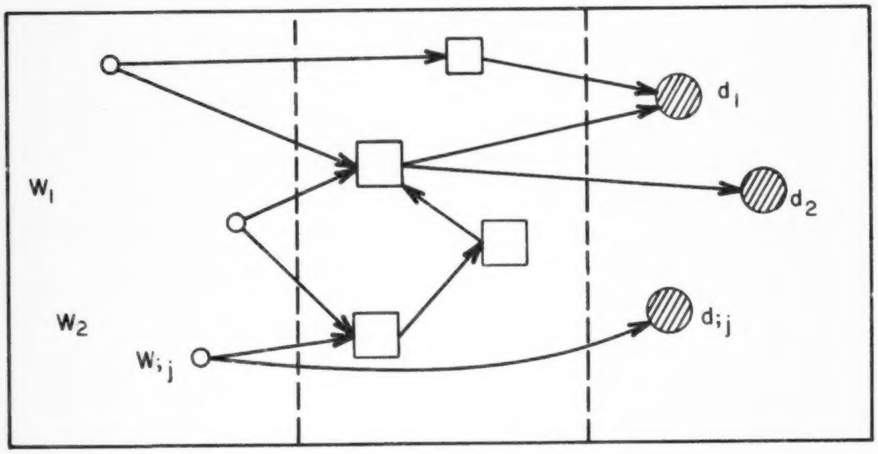


FIGURE 11. WASTE FLOW NETWORK

The sink nodes are points representing final disposal areas. They may take two forms, i.e., recovery destination where the reclaimed waste residues (composting, salvage) are returned to the economy as raw resources, and dump areas such as oceans, landfill, incineration, etc., where wastes are returned to the physical environment.

Corresponding to each column of the T matrix is a directed arc of the form (i, j) representing the possible directional routes or connections from node i to node j for waste flow of type k.[*] Fictitious arcs may be included to represent paths of flow through a node when node costs are considered. By partitioning the index set of the columns of T into four subsets representing arcs between the three node subsets defined earlier, one can see from Figure 11 that the matrix T has a special structure. Here ╳ represents sections of T which may have nonnegative elements and ◯ indicates blocks which contain all zero elements. The set of arcs of the network may be partitioned into four subjects, viz.,

$$A = [(S, I), (S, E), (I, E), (I, I)]$$

$$T = \begin{array}{c|cccc|c} \multicolumn{6}{c}{\text{ARCS}} \\ & (S,I) & (S,E) & (I,E) & (I,I) & \\ \hline I & \times & \bigcirc & \times & \times & \\ S & \times & \times & \bigcirc & \bigcirc & \text{NODES} \\ E & \bigcirc & \times & \times & \bigcirc & \\ \hline \end{array}$$

---

[*] Multiple arcs are allowed between pairs of nodes.

A column vector of waste flow variables, F, is now defined with the general element f_{ij}^{k} equal to the amount of waste flow of type k passing from node i to node j measured in tons per year. The vector column F is of dimension $|A|$, where $|A|$ indicates the number of elements of the arc set A.

At each intermediate point in the waste flow network some form of interchange is possible between the flow variables. These conversions are determined by the technology of the operation represented by the node. Thus, the general interchange coefficient b_{ij}^{k} is defined as the amount of type i flow input to station k per unit of type j flow output from station k. The b_{ij}^{k} comprise the set of coefficients B obtained from the process technology model. One may now represent the conversion of waste and salvage flows in the form of material balance equations. By combining these coefficients with the matrix T, the new coefficient matrix $\overline{T}$ is obtained which represents a network with gains.

Utilizing the set W and D obtained from the waste generator and land use studies, we may now represent in compact form a set of inequalities defining the feasible waste flow as:

$$\overline{T}\,F \quad \begin{matrix} = \\ \geq \\ \leq \end{matrix} \begin{bmatrix} 0 \\ \overline{W} \\ \overline{D} \end{bmatrix} \qquad (1)$$

The first block of equations (corresponding to the = 0 right-hand side) are the conservation of flow equations. The next block (corresponding to $\geq \overline{W}$) represents the requirement that all the generated waste be disposed of. The elements of the column vector $\overline{W}$ are numbers w_{ij} representing the annual number of tons of waste of type i generated at location j, a source node. The last block (corresponding to $\leq \overline{D}$)represents the requirement that disposal area capacities are not exceeded. The elements of the column vector $\overline{D}$ are numbers d_{ij} representing the annual number of tons of waste of type i that can be deposited in sink j.

Additional constraints may be imposed by public health. Included in the public health or environmental constraint, H may be the set of upper bounds on the total amount of gaseous waste flow (smog control). Upper bounds on solid or liquid waste flows on particular arcs may reflect vehicle transportation or sewage trunk line limits. Upper bounds on such flows may also be reflected by plant capacities when considered fixed. Incorporating these upper bounds and the fact that waste flows may not be negative in our model requires the following additional set of constraint equations.

$$0 \leq F \leq K \qquad (2)$$

Where: K represents the vector of upper bounds on the set of waste flows.

The objective is to minimize the total cost of the waste handling system. Thus, we shall define a cost function at each node and arc as some linear function of its flow and location. For the arcs, this function may represent the cost of transportation from node i to node j. If there is a cost on a node we may use the method of expanding it into two nodes and one arc and placing node costs and flow constraints on the simulated arc.

These cost coefficients are arranged in the vector R which we may obtain from the Process Technology (and Land Use) models. Thus, the objective function becomes

$$Z = RF \text{ (to be minimized)} \qquad (3)$$

Where: Z = The total cost of collecting, treating and transporting all types of waste to disposal areas.

R = Cost row vector representing the collection and disposal costs of each arc.

F = Column vector of waste flows of all types through the network.

The problem now is one of minimizing the total cost function Z over the feasible set of constraints defined by Equations 1 and 2. The minimum cost and optimal allocation of flows are designated Z^o and F^o, respectively. The constraints (Equations 1 and 2) and objective function (Equation 3) may be combined to obtain a standard linear program whose special structure may allow the application of more efficient programming techniques.

WASTE GENERATION INPUT AND MANAGEMENT SYSTEM INPUTS

Management System Inputs

The evaluation of alternative waste management systems requires two major types of input data: 1) a description of the collection-treatment-disposal system under study, and 2) a prediction of the waste load for the region and year considered. The former will be in terms of the data represented by [T, D, H, B, R] as described previously. The latter will be in terms of an array of waste quantities (tons per year of type i from source j) represented by the matrix W.

Figure 3 indicates the flow of information required for an evaluation of alternative management systems.* The input data from the bottom of the chart indicates that a separate set of inputs is required for each regional system under evaluation. These inputs are obtained from the Land Use, Public Health, and Process Technology Models shown in Figure 2. The behavior of each management system is evaluated for the same waste input load W. It is the process of estimating W that is the function of the Regional Waste Generation Model.

Waste Generation Model

The input data required to predict W are shown in Figure 12. Most of these data are required to describe the economy of the region under study. Once the economy is adequately defined, with the use of the model an estimate can be made of the level of activity of the economy and its corresponding production of waste in the form required by the evaluation model. We have shown in the figure that the regional economy may be divided into its productive and consumption sectors. The activity levels of each of these sectors and their corresponding levels of waste production are determined by the Regional Economic Model and Waste Generator (Consumption Sector) sub-studies indicated in Figure 10. The results of these two studies may be combined to form an array of waste output quantities represented by the matrix V, whose elements are in terms of annual number of tons of waste of type i generated by all sources of category j. The sources are categorized in terms of specific industries or consumption units within the regional economy, the categories being determined on the basis of different waste generation properties. For example, household units and government units will be treated differently in the

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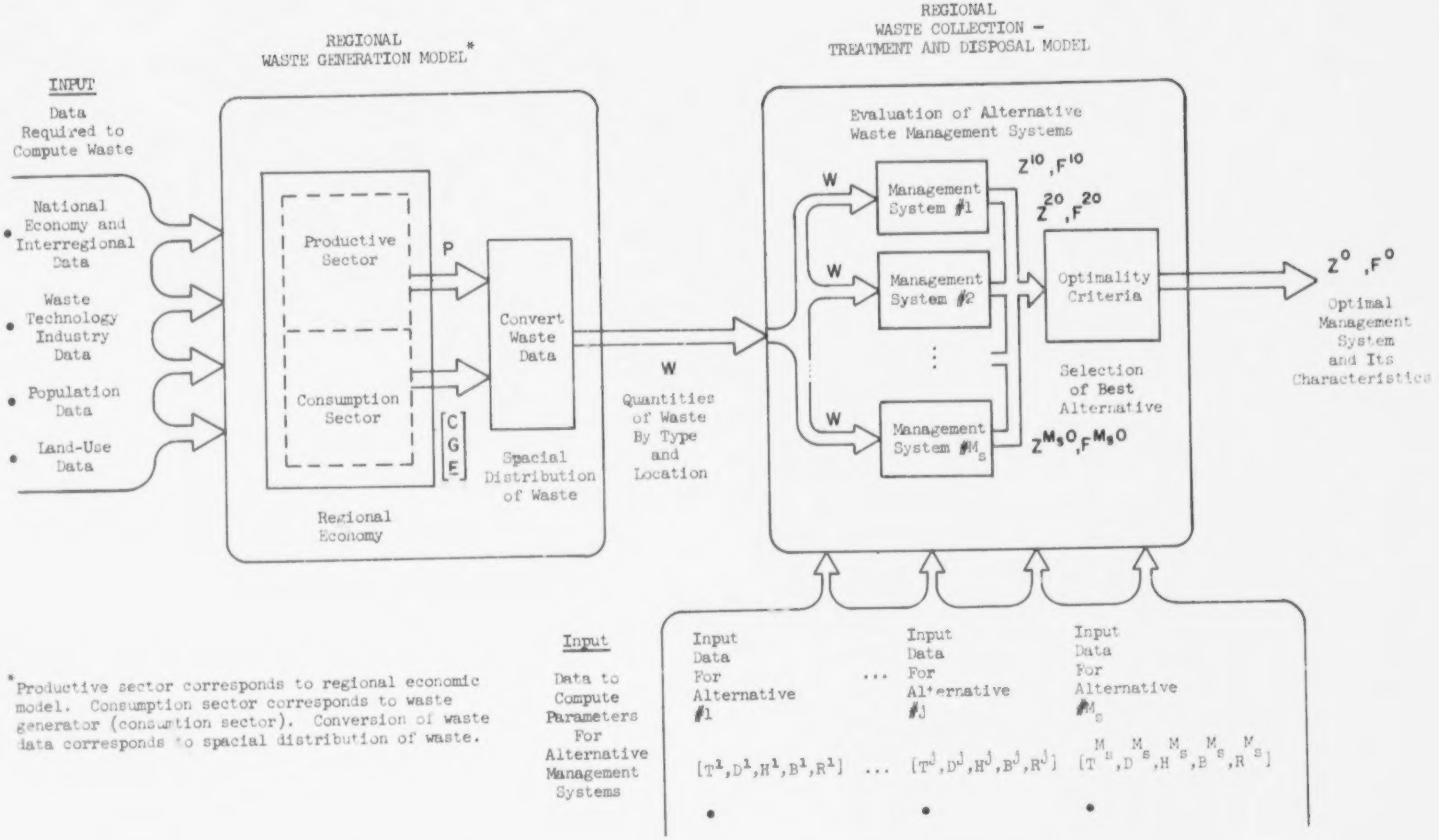
*Examples of alternative management systems may be found in Appendix 2.


REGIONAL
WASTE GENERATION MODEL*
INPUT
Data Required to Compute Waste
National Economy and Interregional Data
Waste Technology Industry Data
Population Data
Land-Use Data
Productive Sector
Consumption Sector
Regional Economy
P
C
G
E
Convert Waste Data
Spacial Distribution of Waste
W
Quantities of Waste By Type and Location
REGIONAL
WASTE COLLECTION -
TREATMENT AND DISPOSAL MODEL
Evaluation of Alternative Waste Management Systems
W
Management System #1
Management System #2
Management System #M_s
Z^{10}, F^{10}
Z^{20}, F^{20}
Z^{M_s0}, F^{M_s0}
Optimality Criteria
Selection of Best Alternative
Z^0, F^0
Optimal Management System and Its Characteristics
Input
Data to Compute Parameters For Alternative Management Systems
Input Data For Alternative #1
$[T^1, D^1, H^1, B^1, R^1]$
Input Data For Alternative #J
$[T^J, D^J, H^J, B^J, R^J]$
Input Data For Alternative #M_s
$[T^{M_s}, D^{M_s}, H^{M_s}, B^{M_s}, R^{M_s}]$

*Productive sector corresponds to regional economic model. Consumption sector corresponds to waste generator (consumption sector). Conversion of waste data corresponds to spacial distribution of waste.

FIGURE 12. MANAGEMENT SYSTEM INPUTS AND WASTE GENERATION MODEL

consumption sector. Since the form of waste data required by the evaluation model is in terms of type of waste and location of origin, the matrix V must be appropriately translated. This is achieved by the Special Distribution of Waste sub-study shown in Figure 11. The three basic sub-studies comprising the Regional Waste Generation Model will now be described in detail.

Regional Economic Model (Productive Sector). The activity levels of the productive sectors of the regional economy may be determined in first approximation through the use of an interindustry input-output model [41-43]. The input-output model takes the following form:

$$X = [I-A]^{-1}Y$$

Where: X = The vector of total output of goods from the productive sector (dollars).

Y = The vector of final demand for goods.

I = The unit matrix.

A = The regional technology matrix.

The primary input to the regional economic model will be the n x n technological coefficient matrix A^{11} representing the n basic industrial sectors of the region under study. The matrix A^{11} will be a result of breaking down $\overline{A}$, the larger state or national input-output matrix, in the Interregional Analysis part of this study.

Additionally, the final demand vector Y^1 for the n basic industries will be obtained from the Interregional Analysis Study. To incorporate the interdependence of the waste disposal industry in the region under consideration with the rest of the regional economy m new industries are defined. Each new industry indexed $j = 1, \ldots m$ represents the service of disposing of waste of a particular characteristic j. The grouping of wastes into m types may be based on such characteristics as garbage, durable, construction waste, wrecked automobiles, liquid wastes, etc. The new variables $x_{n+1}, \ldots, x_{n+j}, \ldots, x_{n+m}$ are incorporated in the vector of total output. The n x n matrix A^{11} is expanded to an $(n + m) \times (n + m)$ matrix A through augmentation of A^{12}, A^{21}, A^{22} obtained from the Waste Process Technology Study for the region. The final demand Y^1, also obtained from the Interregional Analysis is lengthened to Y by adjoining the waste service demand vector Y^2 obtained from the Waste Generator (Consumption Study). The resultant input-output functional equation for the region becomes

$$\begin{array}{l} \begin{array}{c} n \\ \text{Basic Industries} \end{array} \\ \\ \begin{array}{c} m \\ \text{Waste Disposal} \\ \text{Service Industries} \end{array} \end{array} \left\{ \left[\begin{array}{c:c} I - A^{11} & -A^{12} \\ \hdashline -A^{21} & I - A^{22} \end{array} \right] \right. \left[\begin{array}{c} x_1 \\ \vdots \\ x_p \\ \vdots \\ x_n \\ \hdashline x_{n+1} \\ \vdots \\ x_{n+j} \\ \vdots \\ x_{n+m} \end{array} \right] = \left[\begin{array}{c} Y^1 \\ \hdashline Y^2 \end{array} \right]$$

or in matrix form:

$$[I - A]\,X = Y,$$

where: $A^{11} = \left\{a_{ij}\right\} =$ the value of goods or service i in millions of dollars required in the production of one million dollars of production of goods or service j.

$A^{12} = \left\{a_{ij}\right\} =$ the value of commodity i in millions of dollars required by the waste disposal activity to dispose of one ton of waste of type j.

$A^{21} = \left\{a_{ij}\right\} =$ the number of tons of type j waste disposal service required per one million dollars of production by industry j.

$A^{22} = \left\{a_{ij}\right\} =$ the number of tons of type i waste disposal service required per ton of operation of waste disposal service industry j.

By solving this equation for the m + n production levels X enough information is obtained to ascertain the quantity of waste of each type generated by each of the industries. The total amount of waste service of type i required by industry j may be interpreted as the total number of tons of waste of type i generated by industry j in, say, one year of operation. This quantity is represented as:

$$p_{ij} = a_{ij}p_j \text{ for } i = n + 1, \ldots n + m,\ j = 1, \ldots n + m\ .$$

It is the m x (n + m) matrix of $\left\{p_{ij}\right\}$ which we shall designate P. This is the output of the Regional Economic Model. The matrix P represents the quantities and types of waste generated by the productive sector of the economy and is required as an input to the Spacial Distribution of Waste Study.

Waste Generator (Consumption Sector). The purpose of this model is to generate a final waste service demand (m-dimensional) vector Y^2 to be used in the Regional Economic Model and the Spacial Distribution of Waste Studies. This vector is to be attached to the final demand (n-dimensional) vector Y^1 obtained from the Interregional Analysis. The resultant final demand vector Y is expanded to indicate its component parts

$$Y = \left[\begin{array}{c} Y^1 \\ \hline Y^2 \end{array}\right] = \left[\begin{array}{c} C^1 \\ \hline C \end{array}\right] + \left[\begin{array}{c} G^1 \\ \hline G \end{array}\right] + \left[\begin{array}{c} I^1 \\ \hline 0 \end{array}\right] + \left[\begin{array}{c} E^1 \\ \hline E \end{array}\right]$$

where

C^1 = The vector of final household demands for the region under consideration.

C = The vector of household demands for waste disposal service in the region.

G^1 = The vector of the regional governments final demands for goods and services less waste disposal services.

G = The vector of the regional governments demands for waste disposal services.

I^1 = The amount of final demand set aside for investment.

E^1 = Exports of the basic commodities from the region.

E = Exports of waste disposal service. (This for waste generated outside of the region for disposal by the regional waste disposal system).

The final demand vector Y is required by the Regional Economic Model before the industrial production levels and corresponding industrial waste generation quantities may be obtained. The quantities C, G, and E are also required in the Spacial Distribution of Waste Study.

The determination of [C, G, E] will be done by the City Planning Group through a regression analysis study.

Spacial Distribution of Waste. The function of the Spacial Distribution of Waste Model is to provide the waste source points for the Waste Collection, Treatment and Disposal Model. Each waste source point is represented by a quantity of waste of type i which is composed of the cumulative sum of all waste of type i generated by the industrial government and household units located in a specific area k. In areas where waste is deposited from outside the region the total quantity of waste of type i at point k must reflect this. The waste of type i generated at source point k is

$$w_{ik} = w^c_{ik} + w^g_{ik} + w^e_{ik} + w^p_{ik}$$

$$i = 1, \ldots m \qquad k = 1, \ldots K$$

where K = number of sources in the region :

w^c_{ik} = The amount of waste of type i, in tons per year generated by all households in location k.

w_{ik}^{g} = The amount of waste of type i generated per year by all government units in location k.

w_{ik}^{e} = The amount of waste of type i delivered per year to location k from outside the region.

w_{ik}^{p} = The amount of waste of type i in tons per year generated by all industries in location k.

In order to convert the input waste generation data C, G, E, P from its present form of category of origin to the desired form additional information is needed from the Land Use Model. The information required from the Land Use Model is a list of source points representing waste collection points of, say, several blocks square or a census tract. Corresponding to each source point k a set of fractions λ_{jk}^{c}, λ_{jk}^{g}, λ_{jk}^{e}, and λ_{jk}^{p} are needed which indicate the proportion, perhaps of industry j or households of category j located in the area of location k. The matrix of such fractions is designated Λ.

Using these fractions one may now compute the values, magnitudes of wastes, as follows:

$$w_{ik}^{p} = \sum_{j} p_{ij}\lambda_{jk}^{p}$$

$$w_{ik}^{c} = \sum_{j} c_{ij}\lambda_{jk}^{c}$$

$$w_{ik}^{e} = \sum_{j} e_{ij}\lambda_{jk}^{e}$$

$$w_{ik}^{g} = \sum_{j} g_{ij}\lambda_{ij}^{g}$$

where

e_{ij} = The total amount of waste of type i generated outside the region and accepted for disposal by waste disposal service industry j.

g_{ij} = The total amount of waste of type i generated by government unit j.

c_{ij} = The total amount of waste of type i generated by household of category j.

p_{ij} = The total amount of waste of type i generated by industry j.

By appropriate redefinition of variables one may represent the above operations in matrix form as follows:

$$W = V\Lambda = [P, C, G, E] \begin{bmatrix} \Lambda^{p} \\ \Lambda^{c} \\ \Lambda^{g} \\ \Lambda^{e} \end{bmatrix} = W^{p} + W^{c} + W^{g} + W^{e}$$

The dimensions of the above matrices are

W^p, W^c, W^g, W^e, W: $m \times K$

Λ^p: $m + n \times K$

Λ^c: $v \times K$

Λ^g: $q \times K$

Λ^e: $r \times K$

Λ: $[m + n + v + q + r] \times K = s \times K$

P: $m \times m + n$

C: $m \times v$

G: $m \times q$

E: $m \times r$

V: $m \times [n + n + v + q + r] = m \times s$

The linear transformation Λ on the matrix V, in the $m \times s$ space of waste type and origin, to the matrix W in the $m \times k$ space of waste type and location is the basic function performed by the Spacial Distribution of waste operation in Figure 1.

FUTURE EXTENSIONS AND TASKS

A number of extensions to the static evaluation model presented here are considered. Additionally, special studies of alternative management systems are of interest. An outline of some of these extensions and tasks is given below.

1. Dynamic Model: Due to the need for future planning to cope with the process of urban growth the development of a multiperiod dynamic regional model is needed. This model utilizing predicted growth rates and technological change may be used to select optimal future expansion plans of waste management systems.
2. Recovered Waste: Include the process of converting waste to products which may be recycled into the economy.
3. Specialization: A number of alternative management systems must be defined for comparative evaluation. Parts of the basic evaluation may have to be modified for maximum flexibility. Some alternative management systems are mentioned in Appendix 1.
4. Supporting Studies: The optimal design of transfer station characteristics may prove helpful in the evaluation of a management waste collection system composed of a chain of transfer stations. Appendix 2 indicates the start of such a study.
5. Further Development: Further development of the evaluation model may be studied to take advantage of the special structure of the programming problem.

IV. PLANNING AND ECONOMICS

INTRODUCTION

Definitive research in the area of planning and economics proceeded from the general rationale that since some fraction of solid wastes must inevitably be disposed of utilizing land, land-use planning for a community must include some provision for that fact. Conversely, solid wastes management techniques must include considerations of the social, aesthetic, and environmental goals of man as well as his economic attitudes and his technological capabilities at any time. Moreover, the types and amounts of wastes generated under any set of cultural realities and level of economic activity can be predicted on the basis of how many people use how much land for what purposes within a community. Thus the research team concerned with planning and economics directed its particular attention to those aspects of wastes management which relate land use to waste generation. In this activity it worked closely with the operations research team in the establishment and elaboration of appropriate submodels of the overall Waste Generation and Evaluation Model.

The long-term plan of the research team was to approach a series of principal objectives essentially sequentially but with whatever degree of overlapping progress required and the project budget permitted. These objectives in order of research attention were:

1. Formulation of models for studying the structure and relationships between solid waste generation and relevant economic, demographic, and land-use information using selected study regions as examples.

2. Development of pertinent data on quantity and types of solid wastes and related information on economic activities through the establishment of appropriate disposal service areas.

3. Implications of solid wastes generations with respect to land-use planning.

4. Incorporation of technological changes in transportation and disposal of solid wastes.

5. Implications of present and future methods of disposal on private and public expenditure.

In relating these principal objectives, it becomes evident that the research team's concern is primarily with supplying the information needed to develop the submodels for waste generation, land use, population, regional and national economics; and, eventually, process technology.

During the period herein reported, attention was concentrated on the first three of the five principal objectives. Although good progress was made, as hereinafter described, a vast amount of data must be obtained and evaluated before these three objectives can be fully achieved. However, as results become available and are elaborated upon, they will be used in developing the empirical content for the last two objectives (Nos. 4 and 5).

APPROACH AND METHODOLOGY

A research plan and a method of approach was worked out for each of the five principal objectives and serve as the basis for a systematic approach to the stated objectives which is well under way. Obviously, all are subject to modification in the face of realities and the contingencies of research.

Model Formation

Models dealing with waste generation are to be formulated with emphasis on utilizing available economic information and an appropriate analytical framework. A definition is to be made of the various types of solid wastes which are generated in the economy, and the different structures (or models) developed for studying each of the defined wastes. The analytical framework depends mostly on a multiple regression approach wherever the data permit. Simple waste factors per unit of generator will be used only as a last resort when all else fails. For the purpose of formulating structural models, the number of data observations are to be developed on a geographical basis for use in the regression models. Since consistent and comparable data on solid wastes and other related variables are not available for any time periods of significant duration, the analysis to be carried out in this regard must be chiefly a cross-sectional one on a spatial basis, rather than a time series analysis involving time series data. The regressions models, however, will be tested against two types of uses: 1) structural relations to explain the correlation between waste generation and related waste generators, and 2) prediction of future volumes of waste for use in planning formulations. Therefore, development of forecasts (future volumes of solid wastes) will be carried out in two stages with respect to quantity (tons or cubic yards) and to type (composition changes). The latter will have to be developed separately from the regression models since the models cannot be used in predicting changes in composition on a qualitative basis. The actual development of this work will probably be done in cooperation with the Operations Research team.

Data on total solid wastes will be divided according to origin into one of the following classes: household wastes, commercial and services establishments, industrial (manufacturing, food and nonfood), agricultural, and special wastes (such as junked automobiles, etc.). These classifications can be further divided as the need arises.

Independent variables to be considered in studying each type of waste may involve one or more of the following: population, number of households, per capita or household income, employment, and land use. The level of industrial activities can be introduced either by way of employment figures or, if data are available, by output.

As previously mentioned, the analytical approach involves fitting regression equations by least squares method of estimation for different types of wastes. The success of this approach depends upon the number of independent observations that can be collected on a cross section basis for each type of waste.

The following is a tentative specification of variables for the regression study.

Waste	As a Function of
a. Household	Population and income
b. Commercial and Services	Size (measured by employment)
c. Manufacturing	Size* Employment level or activity nature*
d. Agricultural	Land use
e. Special	
Municipal	
Street refuse	Population
Sewage sludge	
Vehicles Abandoned	No. of automobiles and distribution by age
Demolition and Construction	No. of old buildings and new developments (To be elaborated upon)

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*To be specified in detail.

Development of Pertinent Data on Quantity and Types of Solid Wastes

The development of corresponding sets of waste data and related economic variables is an essential part of empirical model building to be used throughout the second year of the project. The enormity of the amount as well as the complexity of the nature of the data required to accomplish such an undertaking was demonstrated in a pilot study carried out (and hereinafter reported) with Santa Clara County as the subject area. Though of itself the pilot study did not result in the production of a model, it did provide the necessary insight into the formulation of models, planning of the data requirements, and the amount of resources that go into development of these requirements.

With respect to data collection, a disposal service area is herein defined as one consisting of a group of census tracts for which data on the generation of solid wastes are available. For example, if a disposal site receives all of the wastes generated from a particular region, that region would be defined as a disposal service area. On the other hand, if there are two or more disposal sites that receive solid wastes from two or more overlapping regions, then a single disposal service area is defined to consist of those disposal sites and the corresponding larger region. By resorting to such a definition, the problems involved in arbitrarily splicing geographic regions are eliminated, and thereby the computation of consistent and comparable data on wastes and economic activity is facilitated. This definition of a disposal area was used in dividing the nine counties of the San Francisco Bay area into meaningful disposal service areas, which become the geographical units for the development of primary information for the regression model. This arrangement will also facilitate the comparison of several regions as needed in future work.

Since the collection of the data necessitates the interviewing of disposal site operators and various (county and city) public health agencies, and since a project involving such a collection already has been undertaken by the California State Department of Public Health, research efforts of the planning team are to be coordinated with those of the State so as to obtain the data with a minimum number of contacts with the local public health officials. Once the disposal service area boundaries are drawn, the data on several variables can be collected and tabulated for analysis. The plan is first to draw up a set of disposal service areas (defined in terms of actual census tracts) in close consultation with the State Department of Public Health. After doing this, the collection of economic information will proceed county by county by our own group in conjunction with the various local (county and city) planning groups and other published sources of data. The various items of economic data which we shall collect for analysis are listed in Appendix C.

Solid Waste Generation and Land Use Planning

Since a consideration of waste disposal is an essential feature of any well conceived plan of land use, a part of the study will be devoted to making an evaluation of the effect of conventional and future methods of waste disposal on land use planning. The basic inputs for this item of study consist of data and forecasts which would become available from the studies of the Bay Area Transportation Study Commission. These studies already have utilized in a large measure all pertinent and latest information on land use by small geographic parcels (sometimes city blocks). The forecasts of land use are developed under alternate traffic generation plans and vice versa. The results will be used effectively to provide feedback effects of the regional evaluation models of waste generation and land use.

Some of the specific issues of concern are as follows:

1. Projection of solid waste volume — related land-use requirements based on continuation of existing methods of disposal (landfill).
2. Changes in land-use requirements with respect to overall urban land-use planning.
3. Location of future disposal sites and land-use planning.

The above items are to be considered in terms of their regional implications and regional solutions versus local efforts based on local solutions to problems.

Since refuse disposal is recognized as one of the major items for regional planning by the Association of Bay Area Governments, Bay Conservation and Development Commission, and other agencies, the regional planning implications will be explicitly stated in terms of magnitude of the problem and the potentialities that would arise by a regional approach. Several considerations in formulating such a regional plan consist of investigations of the structure of transportation and disposal "plant" costs.

Another item of work consists of communication with the local planning groups in examining their urban land-use plans and the extent of recognition of waste disposal sites in the overall urban land-use plan.

Incorporation of Technical Changes in Transportation and Disposal of Solid Wastes

As additional information is made available concerning present and future methods of waste disposal, it will be used to assess the impact of the practical application of these methods. This involves the examination of solid waste data in greater depth by source, physical content and properties, by different geographic regions, vis-a-vis new technologies proposed. This item of work awaits development in the engineering methods and would be given priority toward the end of the second year and subsequent period of research.

As specification of work items, the following is contemplated:

1. A list will be made of each method of disposal (e.g., landfill, composting, incineration, biooxidation, wet oxidation, etc.) either as presently employed or as proposed.

2. For each method of disposal, obtain in detail the nature of the physical requirements (such as physical/chemical composition, carbon, nitrogen content, caloric value, etc.) relating to the solid waste.

3. The capital requirements for setting up the plants and recurring maintenance expenditures, and related cost information will be determined.

4. The method or methods in question in terms of their feasibility for a particular region will be evaluated.

Implications of Present and Future Methods of Disposal on Private and Public Expenditure

This area of research will be formulated in greater detail during the second and third years of the research period. The development of this item of research should await a full-scale development of analytical models of waste generation, associated costs, possible changes in methods of transportation and disposal, and an elucidation of their implications on land and of new technologies on capital and maintenance expenditures on the community. Specific plan of work on this item will be formulated during the end of the second year of the project. For the present, the following breakdown of subitems of work are suggested for future reference.

1. Analysis of private and public expenditure by functions, (transportation, disposal, supervision, etc.).

2. Changes in present methods — causing changes in transportation costs, and/or disposal costs.

3. Effect on existing public expenditures on health, planning, and in general on supervisory activities of public bodies.

The analysis of the above items could be carried out in those areas for which the detailed analytical models envisaged in objectives 1 through 4 are developed. For example, as a beginning attention could be concentrated on the nine-county Bay region which may serve as a laboratory for an empirical study. Other areas of the state could be taken up subsequently to check the general validity of conclusions drawn from the test case (Bay region), depending upon the success of data collection efforts.

Finally, this item of work could treat the various combinations of solutions (involving transportation and disposal methods) in the overall perspective or regional evaluation of waste disposal techniques.

SANTA CLARA COUNTY STUDY

Introduction

As noted in a preceding chapter Santa Clara County was selected as a suitable laboratory area in which to develop generally valid interrelationships because of its urban-suburban-industrial-agricultural characteristics. It was therefore used by the planning and economics research team in an empirical pilot study, the objectives of which were to explore the field and to formulate a detailed plan of work relative to the three initial objectives previously noted. The study was not intended to supply definitive answers to the waste management problems of the county, inasmuch as such an undertaking would require resources and research beyond the scope of the present project. The additionally required research work would center mainly around two areas, viz., forecasting future volumes of waste, and analysis of private and public expenditures at various local levels. Instead of being considered as a means of attaining a solution, the reported study should be regarded as an effort to provide the necessary insight into the level and complexity of the detailed nature of data to be collected for defining, analyzing, and attempting to solve the solid waste management problem.

Four factors were explored in detail:

1. Location of disposal sites and definition of service areas.
2. Land use and employment.
3. Solid waste generation.
4. Composition of solid wastes.

To obtain data on these factors, it was necessary to interview officials of the planning, health, and other appropriate agencies, as well as public and private dump operators and scavengers. The data were then used to formulate a regression study.

Location of Disposal Sites and Definition of Disposal Service Areas

There are 27 sites in Santa Clara County which are currently in operation. These sites can be classified as 1) sites primarily used by scavenger companies with regular collecting schedules and routes, 2) sites primarily used as public trash sites by the general public and private haulers, 3) sites used for disposal of cannery wastes, and 4) sites used for special purposes. This classification is helpful in making estimates of the volume of solid waste that go into various sites. Waste going into class 1 sites can be estimated by interviewing the site operators or the scavenging company using the sites (sometimes the same as the site operator). These estimates are fairly accurate depending upon whether or not the material is weighed on scales. In the case of class 2 sites, served mostly by the general public, estimates of quantities are necessarily crude and are separated from other categories. Cannery wastes data can be obtained from the special private haulers who serve the canneries. Special sites, class 4, are considered separately because the nature and volume of material coming into these sites can be highly seasonal and unique in nature. Examples of the latter are auto junk yards, park sites, special demolition sites, etc. A list of the sites in Santa Clara County is given in Table 17, and their locations are shown on the county map in Figure 13.

Once the sites had been located the next step was to obtain data on the quantity of solid waste material that was delivered to a given site during a certain period of time from a specified region that could be defined. In order to keep the estimating problem manageable and at the same time establish a concept that is extensively used for estimation purposes, the notion of a disposal service area (DSA) was conceived. It is arbitrarily defined as an area that consists of a group of census tracts, contiguous or noncontiguous, and related to one or more disposal sites located within or outside the area. In some cases a census tract is broken and only the pertinent part of it is included in the DSA. The notion of DSA is used in order to define a reference region not too small for practical purposes and yet not so large as to obscure the different characteristics of the waste data to be collected. The idea of DSA is also helpful in avoiding the arbitrary drawing of boundaries to correspond to each and every disposal site. It often happens that solid waste material generated in an area does not always end up in a single disposal site, and the service boundary for each disposal site overlaps as described schematically in Figure 14. In order to avoid the abritrary splicing of boundaries for each of the sites (A and B) a single DSA is defined, comprised of the two overlapping regions.

In line with this concept of DSA, the service area boundaries for the various disposal sites in Santa Clara County were drawn in consultation with the county public health officials, who are aware of up-to-date information relating to sites and collection areas. The boundaries of the DSA's utilized in the study are shown on the map in Figure 13. The problem of defining disposal service areas is especially difficult in the San Jose (a city in Santa Clara County) area, an area in which there are nearly 11 sites, each differing in nature. Drawing on individual boundary for each of the sites would be most cumbersome. Therefore, seven DSA's were defined for the urban areas of the county. The remainder of the county was defined as the 8th DSA to complete the statistical picture. The DSA's and the corresponding sites are given in Table 18.

The DSA's were further defined in terms of the corresponding census tracts that fall within the area, and in terms of planning areas used by the County Planning Department for data collection and analysis. These classifications are indicated in Table 19. This information is very useful for collecting and grouping individual data items to correspond to the DSA's for comparison and analysis of data on solid wastes.

Land-Use and Employment Data

The basic land-use data are related to 1962 and were given by census tracts for each major type of activity — agriculture, manufacturing, services, etc. The basic employment data were, however, available only by broad categories called labor market areas. Therefore, a good deal of splicing had to be done before these data could be compiled by disposal service area.

The 1962 land-use data according to census tracts was first grouped according to planning areas (or portions thereof where needed) and checked against available information. The planning area subtotals were then used to develop land use by disposal service areas. The remainder of the county (8th DSA) was obtained as a residue from the county total. The land-use data sources and calculations are indicated in Tables 20 and 21.

As mentioned before, the basic data on employment relate to "labor market areas" as defined by the labor market analysts of the Department of Employment.

TABLE 17

SOLID WASTE DISPOSAL SITES IN SANTA CLARA COUNTY

I. Sites Served Primarily by Scavenger Companies:

1. Palo Alto Municipal Disposal Site
2. Mountain View Disposal Site
3. Sunnyvale City Disposal Site
4. Gilroy Disposal Site
5. Pacheco Pass Disposal Site
6. Morgan Hill Disposal Site
7. Guadalupe Disposal Site
8. Los Altos Ranch Disposal Site
9. City of Santa Clara Disposal Grounds
10. Newby Island Disposal Site
11. Eastside Disposal Site
12. Customer Utility Service Site

II. Public Trash Sites:

13. Stierlin Road Disposal Site
14. Edgewater Disposal Grounds
15. Storey Road Disposal Grounds
16. Singleton Road Disposal Grounds
17. City of San Jose Disposal Site
18. San Martin Disposal Site

III. Cannery Waste Disposal Sites:

19. Woelfel Ranch
20. Hessler Ranch
21. Silviera Ranch
22. Collier Charcoal Co. Site
23. Pierce Ranch
24. Thuer Ranch
25. Carroll Ranch
26. Furtado Ranch

IV. Special Sites:

27. Mt. Madonna Park Site (refuse from county park only)

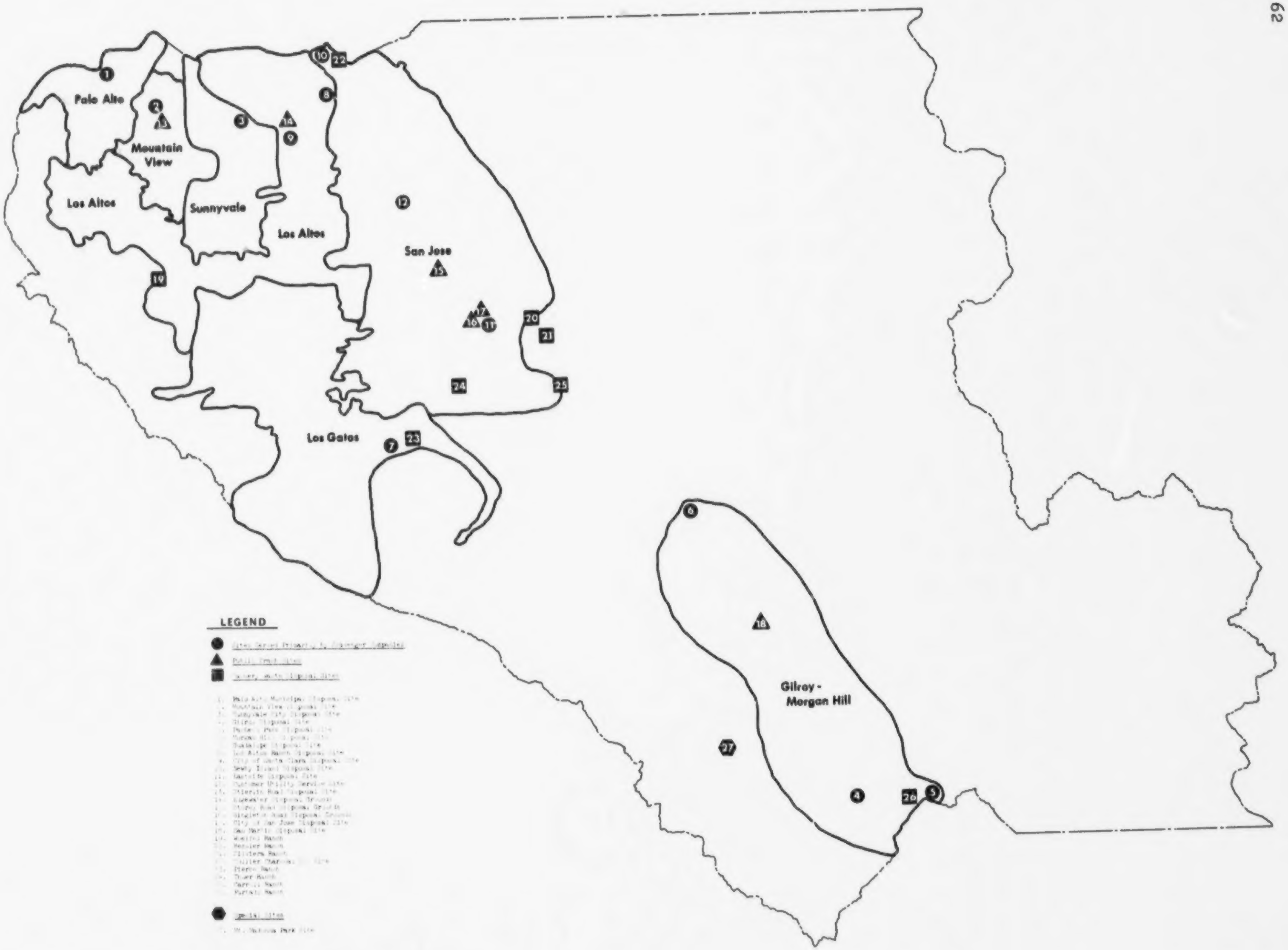
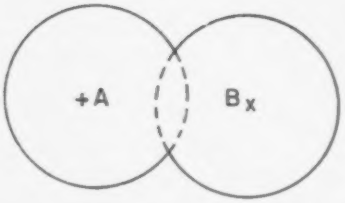

Palo Alto
Mountain View
Los Altos
Sunnyvale
Los Altos
San Jose
Los Gatos
Gilroy - Morgan Hill
1
2
13
3
14
9
8
10
22
12
15
17
16
11
20
21
24
25
19
7
23
6
18
27
4
26
5
LEGEND
Sites Served Primarily by Scavenger Companies
Public Trash Sites
Other Waste Disposal Sites
1. Palo Alto Municipal Disposal Site
2. Mountain View Disposal Site
3. Sunnyvale City Disposal Site
4. Gilroy Disposal Site
5. Pacheco Pass Disposal Site
6. Morgan Hill Disposal Site
7. Guadalupe Disposal Site
8. Los Altos Ranch Disposal Site
9. City of Santa Clara Disposal Site
10. Newby Island Disposal Site
11. Eastside Disposal Site
12. Customer Utility Service Site
13. Stierlin Road Disposal Site
14. [illegible] Disposal Grounds
15. Story Road Disposal Grounds
16. Singleton Road Disposal Grounds
17. City of San Jose Disposal Site
18. San Martin Disposal Site
19. [illegible] Ranch
20. Hessler Ranch
21. [illegible] Ranch
22. Collier Charcoal [illegible] Site
23. Pierce Ranch
24. Tower Ranch
25. Carroll Ranch
26. Furtado Ranch
Special Sites
27. Mt. Madonna Park Site

FIGURE 13. SOLID WASTE DISPOSAL SITES AND SERVICE AREAS, SANTA CLARA COUNTY



NOTE: SITE A AND SITE B HAVE AN OVERLAPPING SERVICE AREA BOUNDARY DENOTED BY DOTTED LINES

FIGURE 14. SCHEMATIC DESCRIPTION OF OVERLAPPING DISPOSAL SITES

TABLE 18

DISPOSAL SERVICE AREAS AND CORRESPONDING DISPOSAL SITES IN SANTA CLARA COUNTY

Disposal Service Area	Disposal Sites Included
Palo Alto	Palo Alto Municipal Disposal Site (1)
Mountain View	Mountain View Disposal Site (2) Stierlin Road Disposal Site (13)
Sunnyvale	Sunnyvale City Disposal Site (3)
Gillroy-Morgan Hill	Gilroy Disposal Site (4) Pacheco Pass Disposal Site (5) Morgan Hill Disposal Site (6) San Martin Disposal Site (18) Furtado Ranch (26)
Los Gatos	Guadalupe Disposal Site (7) Pierce Ranch (23)
Los Altos	Los Altos Ranch Disposal Site (8) City of Santa Clara Disposal Grounds (9) Edgewater Disposal Grounds (14) Woelfel Ranch (19)
San Jose	Newby Island Disposal Site (10) Eastside Disposal Site (11) Customer Utility Service Site (12) Storey Road Disposal Grounds (15) City of San Jose Disposal Site (17) Singleton Road Disposal Grounds (16) Thuer Ranch (24) Hessler Ranch (20) Collier Charcoal Co. Site (22) Silviera Ranch (21) Carroll Ranch (25)

Note: The boundaries of the various disposal service areas are defined in such a way that the amount of total solid wastes generated and the origin of wastes could be identified for the purposes of analysis in this study. The boundaries of each of the disposal service areas are defined in terms of the census tracts (see next table).

TABLE 19

DEFINITION OF DISPOSAL SERVICE AREAS BY PLANNING AREAS AND CENSUS TRACTS IN SANTA CLARA COUNTY

Disposal Service Area	Corresponding Planning Area[a]	Corresponding Census Tracts
(1) Palo Alto Disposal Service Area	O	106-116
(2) Mt. View Disposal Service Area	N_1	92-99
	M_1	91A
(3) Sunnyvale Disposal Service Area	M_2	84-90, 91B
	L_1	82-83
	F	46-47
(4) Gilroy-Morgan Hill Disposal Service Area	X	125-126
	W	124
	V	123
(5) Los Gatos Disposal Service Area	R_1	119B
	K	73-76
	Q	118
	J_1	68A, 68C, 69-72
	A_1	26-28
	I	62-66, 67
(6) Los Altos Disposal Service Area	L_2	77-81
	N_2	100-105
	P	117A, 117B
	H_1	52-57, 59-61
(7) San Jose Disposal Service Area	S	120
	A_2	1-25, 29-32
	R_2	119A
	B	33-35
	C	36-42
	H_2	51, 58
	J_2	68B
	G	48, 49, 50
	D	43
	E	44-45
(8) Remainder of County	T	121
	U	122
	Y	127

[a] A planning area is a collection of census tracts which in some cases roughly correspond to municipal limits. These divisions of the county are the same as U.S. county census divisions. The planning areas are identified by alphabets A through Y. In the case of some of the definitions of Disposal Service Areas, it was necessary to break down a planning area to coincide with the boundaries of service areas. The corresponding portions of planning areas are denoted with subscripts 1 and 2 and are further identified with the census tracts that fall within those portions.

TABLE 20

LAND USE BY PLANNING AREAS AND PORTIONS OF PLANNING AREAS
FOR SELECTED LAND-USE CATEGORIES, 1962,
SANTA CLARA COUNTY

County Planning Areas	Census Tracts	Agriculture[a]	Urban Developed Area[b]			
			Manufacturing	Transportation, Communications, & Utilities	Commercial (Wholesale & Retail Trade; Finance, Insurance,+ Real Estate Services)	Government (Public & Quasi Public Buildings)
A_1	(26-28)	678	0	451	89	57
A_2	(1-25, 29-32)	8,060	621	4,199	1,270	732
B	(33-35)	20,470	32	773	57	71
C	(36-42)	5,214	47	878	186	133
D	(43)	8,723	49	468	189	20
E	(44-45)	111,875	213	592	52	72
F	(46-47)	12,575	527	1,862	78	22
G	(48-50)	6,943	163	773	88	778
H_1	(52-57, 59-61)	3,134	500	1,372	412	238
H_2	(51, 58)	853	113	613	136	12
I	(62-67)	3,343	28	1,265	299	173
J_1	(68A, 68C, 69-72)	8,499	14	1,065	146	123
J_2	(68B)	156	0	101	10	14
K	(73-76)	7,578	10	723	54	167
L_1	(82-83)	1,079	5	355	49	38
L_2	(77-81)	6,110	30	941	153	124
M_1	(91A)	980	100	172	54	10
M_2	(84-90, 91B)	3,450	266	938	264	139
N_1	(92-99)	1,449	75	780	329	193
N_2	(101-105)	1,073	4	755	118	215
O	(106-116)	3,805	362	1,582	397	1,744
P	(117)	29,150	272	809	21	216
Q	(118)	34,070	0	697	8	104
R_1	(119B)	15,292	0	247	12	9
R_2	(119A)	450	6	75	19	23
S	(120)	14,872	183	572	33	7
T	(121)	16,819	1	359	26	76
U	(122)	64,081	6	511	1	2
V	(123)	20,677	35	647	67	30
W	(124)	20,071	18	667	40	11
X	(125-126)	29,495	62	949	137	40
Y	(127)	369,541	3,080	939	12	46

Sources: Santa Clara County Planning Department, Land Use Summary, 1962--Planning Areas, Information No. 142, and some unpublished tables giving data by census tracts.

[a] Table A of the above report.

[b] Table C of the above report. The information is given as percentage of urban developed area by four broad categories. Urban developed area is defined as equal to total land area less land in extractive industries, metropolitan and regional parks, agriculture, open, and vacant urban land.

TABLE 11

LAND USE BY DISPOSAL SERVICE AREAS
FOR SELECTED LAND USE CATEGORIES, 1962,
SANTA CLARA COUNTY
(acres)

County Planning Areas & Corresponding Disposal Service Areas	Agriculture	Manufacturing	Transportation, Communications, & Utilities	Commercial (Wholesale & Retail Trade; Finance, Insurance, & Real Estate Services)	Government (Public & Quasi Public Buildings)
Planning Area O	3,805	362	1,582	397	1,744
Palo Alto Disposal Service Area	3.805	362	1,582	397	1,744
Planning Area N_1	1,449	75	780	329	193
Planning Area M_1	980	100	172	54	10
Mountain View Disposal Service Area	2,429	175	952	383	203
Planning Area M_2	3,450	266	938	264	139
Planning Area L_1	1,079	5	355	49	38
Planning Area F	12,575	527	1,862	78	22
Sunnyvale Disposal Service Area	17,104	798	3,155	391	199
Planning Area V	20,677	35	647	67	30
Planning Area W	20,071	18	667	40	11
Planning Area X	29,495	62	949	137	40
Gilroy-Morgan Hill Disposal Service Area	70,243	115	2,263	244	81
Planning Area R_1	15,292	0	247	12	9
Planning Area K	7,578	10	723	54	167
Planning Area Q	34,070	0	697	8	104
Planning Area J_1	8,499	14	1,065	146	123
Planning Area A_1	678	0	451	89	57
Planning Area I	3,343	28	1,265	299	173
Los Gatos Disposal Service Area	69,460	52	4,448	608	633
Planning Area L_2	6,110	30	941	153	124
Planning Area N_2	1,073	4	755	118	215
Planning Area P	29,150	272	809	21	216
Planning Area H_1	3,134	500	1,372	412	238
Los Altos Disposal Service Area	39,467	806	3,877	704	793
Planning Area S	14,872	183	572	33	7
Planning Area A_2	8,060	621	4,199	1,270	732
Planning Area R_2	450	6	75	19	23
Planning Area B	20,470	32	773	57	71
Planning Area C	5,214	47	878	186	133
Planning Area H_2	853	113	613	136	12
Planning Area J_2	156	0	101	10	14
Planning Area G	6,943	163	773	88	778
Planning Area D	8,723	49	468	189	20
Planning Area E	111,875	213	592	52	72
San Jose Disposal Service Area	177,616	1,427	9,044	2,040	1,862
Planning Area T	10,819	1	359	26	76
Planning Area U	64,081	6	511	1	2
Planning Area Y	369,541	3,080	939	12	46
Remainder of County	450,441	3,087	1,809	39	124
Total County	830,565	6,822	27,130	4,806	5.639

Source: Table 10

Six labor market surveys have been carried out with respect to different parts of the Santa Clara County. The surveys are carried out every two years and the reference period is the month of July. The data used here relate to July 1964.

Before using the employment data, however, it was necessary to reconcile the classifications of economic activity both for land use and for employment data. Accordingly, the following categories were defined: Agriculture; Manufacturing; Transportation, Communication and Utilities; Commercial (wholesale, retail trade, finance, real estate, and insurance); and Government – public and quasi public buildings. These classifications are necessarily broad at this stage, but could be broken down in detail according to the Standard Industrial Classification Code.

The employment data as obtained from Labor Market Survey (1964) are given against each row total in Table 22.

The next step was to develop employment data by disposal service areas based on labor market survey totals. To do this, each labor market area was defined in terms of the component planning area (or portions thereof). For example, Palo Alto community labor market area is broken down into Planning Areas, O, P, N_1, and N_2. (The planning areas are in turn defined in terms of census tracts – Table 19, but are not needed for this purpose.) Using the corresponding land-use data by planning areas (Table 20) as the basis for each of the categories of employment, the total for the labor market area is broken down into components. These calculations are carried out for each of the five categories of employment and for each of the six labor market area totals (see Table 22). By simply rearranging the planning areas to correspond to the DSA's (Table 19), the desired DSA totals may be obtained. These totals are listed in Table 23.

Solid Waste Data

Data on solid waste were collected with the use of a questionnaire especially designed for the purpose. A copy of the questionnaire is shown in Appendix D. The various disposal site operators in the county were interviewed with the help of the County Public Health Department to obtain data on the volume of solid waste received at the site, composition of the wastes, data on site capacities, labor, material and equipment employed at the disposal site, and finally cost of disposal. The data on solid waste are summarized in Table 24. It would appear from a first look, that the level of detail obtained is far from satisfactory for any comprehensive mathematical model building related to solid waste generation. The composition of waste reported is highly aggregated and does not permit detailed classification of total solid waste into types of waste and related economic activity.

The disposal site cost data were incomplete and a different approach had to be used in estimating these costs. The actual data on labor, material, and equipment used on the site were used in conjunction with rental charges to derive comparable costs of disposal on each disposal site. The data are summarized in Table 25.

Composition of Solid Waste

The data on the composition of solid waste were derived for each of the disposal service areas with the use of the data collected in the interviews. Corresponding data on population and employment also were derived from earlier calculations. All of the comparable data are presented in a tabular form in Table 26. The development of such tables in more detail than hitherto has been possible is a prerequisite for any systematic approach to solid waste generation studies.

Regression Study

Some of the data developed in the study can be used for developing regression models to study waste generation as a function of economic activities. Due to a

TABLE 22

EMPLOYMENT BY PLANNING AREAS, JULY 1964
SANTA CLARA COUNTY

Labor Market Communities & Corresponding County Planning Areas	Agriculture			Manufacturing			Transportation, Communications & Utilities			Commercial (Wholesale & Retail Trade; Finance, Insurance, & Real Estate Services)			Government (Public & Quasi Public Buildings)		
	Land,[a] acres	% Dist'n	Employment	Land,[a] acres	% Dist'n	Employment	Land,[a] acres	% Dist'n	Employment	Land,[a] acres	% Dist'n	Employment	Land,[a] acres	% Dist'n	Employment
Planning Area O	3,805	10.8	34	362	50.8	11,278	1,582	40.3	847	397	45.9	22,445	1,744	73.6	6,624
Planning Area P	29,150	82.2	264	272	38.1	8,458	809	20.6	433	21	2.4	1,174	216	9.1	819
Planning Area N$_1$	1,449	4.0	13	75	10.5	2,331	780	19.9	417	329	38.0	18,582	193	8.2	738
Planning Area N$_2$	1,073	3.0	10	4	.6	133	755	19.2	403	118	13.7	6,699	215	9.1	819
Palo Alto Community Labor Market Total	35,477	100.0	321	713	100.0	22,200	3,926	100.0	2,100	865	100.0	48,900	2,368	100.0	9,000
Planning Area J$_1$	8,499	36.2	310	14	23.7	402	1,065	33.4	267	146	35.4	2,796	123	26.4	528
Planning Area J$_2$	156	.7	6	0	0.0	0	101	3.2	26	10	2.4	190	14	3.0	60
Planning Area K	7,578	32.4	777	10	16.9	287	723	22.7	182	54	13.1	1,035	167	35.8	716
Planning Area L$_1$	1,079	4.6	40	5	8.5	146	355	11.1	89	49	11.9	940	38	8.2	164
Planning Area L$_2$	6,110	26.1	223	30	50.9	865	941	29.6	236	153	37.2	2,939	124	26.6	532
Los Gatos Community Labor Market Total	23,422	100.0	856	59	100.0	1,700	3,185	100.0	800	412	100.0	7,900	466	100.0	2,000
Planning Area A$_1$	678	1.0	39	0	0.0	0	451	4.3	288	89	3.3	2,663	57	4.0	852
Planning Area A$_2$	8,060	12.3	480	621	39.5	13,983	4,199	39.7	2,660	1,270	47.7	38,493	732	50.7	10,799
Planning Area B	20,470	31.3	1,224	32	2.0	708	773	7.3	489	57	2.1	1,695	71	4.9	1,044
Planning Area C	5,214	8.0	312	47	3.0	1,062	878	8.3	556	186	7.0	5,649	133	9.2	1,960
Planning Area D	8,723	13.4	523	49	3.1	1,097	468	4.4	295	189	7.1	5,730	20	1.4	298
Planning Area H$_1$	3,134	4.8	187	500	31.8	11,266	1,372	12.9	866	412	15.3	12,380	238	16.5	3,506
Planning Area H$_2$	853	1.3	51	113	7.2	2,540	613	5.8	387	136	5.1	4,083	12	0.8	177
Planning Area I	3,343	5.1	199	28	1.8	637	1,265	11.9	797	299	11.2	9,038	173	12.0	2,556
Planning Area S	14,872	22.8	891	183	11.6	4,107	572	5.4	362	33	1.2	968	7	.5	106
San Jose Community Labor Market Total	65,336	100.0	3,906	1,575	100.0	35,400	10,588	100.0	6,700	2,666	100.0	80,700	1,442	100.0	21,300
Planning Area F	12,575	73.9	394	527	59.0	14,042	1,862	62.6	626	78	19.7	2,383	22	12.9	658
Planning Area M$_1$	980	5.8	31	100	11.2	2,666	172	5.8	58	54	13.6	1,646	10	5.8	296
Planning Area M$_2$	3,450	20.3	109	266	29.8	7,092	938	31.6	316	264	66.7	8,071	139	81.3	4,146
Sunnyvale Community Labor Market Total	17,005	100.0	534	893	100.0	23,800	2,972	100.0	1,000	396	100.0	12,100	171	100.0	5,100
Planning Area E	111,857	94.2	503	213	56.6	1,245	592	43.4	43	52	37.1	519	72	8.5	179
Planning Area G	6,943	5.8	31	163	43.4	955	773	56.6	57	88	62.9	881	778	91.5	1,921
Milpitas Community Labor Market Total	118,800	100.0	534	376	100.0	2,200	1,365	100.0	100	140	100.0	1,400	851	100.0	2,100
Planning Areas W, X, V Gilroy Community Labor Market Survey Total[b]			1,336			1,800			400			2,000			900
Planning Areas[c] NOT in Community Labor Market Surveys															
Planning Area Q	34,070			0			697			8			104		
Planning Area R$_1$	15,292			0			247			12			9		
Planning Area R$_2$	450			6			75			19			23		
Planning Area T	16,819			1			359			26			76		
Planning Area U	64,081			6			511			1			2		
Planning Area Y	369,541			3,080[d]			939			12			46		

Procedure for obtaining employment estimates by disposal service areas:

As part of the Labor Market Survey work, employment data by major categories are published for each of the six "labor market communities" in Santa Clara County. The labor market communities could be defined in terms of planning areas or portions thereof.

For each of the labor market communities, the employment (for each of the major categories) is divided into components corresponding to the planning areas using the land use information as the basis. For details, see text.

[a] From Table 20.
[b] Gilroy Community Labor Market Survey corresponds to the Gilroy-Morgan Hill Disposal Service Area used in this study. Hence, no further breakdown into Planning areas was necessary.
[c] These planning areas of the county are not included in any of the Community Labor Market Surveys.
[d] This parcel is entirely the United Technology Development Center at Coyote.

TABLE 25

EMPLOYMENT BY DISPOSAL SERVICE AREAS, 1964
SANTA CLARA COUNTY

County Planning Areas & Corresponding Disposal Service Area	Agriculture	Manufacturing	Transportation, Communications, & Utilities	Commercial (Wholesale & Retail Trade; Finance, Insurance, & Real Estate Services)	Government	Total Employment	Employment Excluding Agriculture
Planning Area O	34	11,278	847	22,445	6,624	41,228	41,194
Palo Alto Disposal Service Area Total	34	11,278	847	22,445	6,624	41,228	41,194
Planning Area N_1	13	2,331	417	18,582	738	22,081	22,068
Planning Area M_1	31	2,666	58	1,646	296	4,697	4,666
Mt. View Disposal Service Area	44	4,997	475	20,228	1,034	26,778	26,734
Planning Area M_2	109	7,092	316	8,071	4,146	19,734	19,625
Planning Area L_1	40	146	89	940	164	1,379	1,339
Planning Area F	394	14,042	626	2,303	658	18,103	17,709
Sunnyvale Disposal Service Area	543	21,280	1,031	11,314	4,968	39,216	38,673
Planning Areas V, W, X	1,338	1,800	400	2,000	900	6,438	5,100
Gilroy-Morgan Hill Disposal Service Area	1,338	1,800	400	2,000	900	6,438	5,100
Planning Area R_1	-	-	-	-	-	-	
Planning Area K	277	287	182	1,035	716	2,497	2,220
Planning Area Q	-	-	-	-	-	-	
Planning Area J_1	310	402	267	2,796	528	4,303	3,993
Planning Area A_1	39	0	288	2,663	852	3,842	3,803
Planning Area I	199	637	797	9,038	2,556	13,227	13,028
Los Gatos Disposal Service Area	825	1,326	1,534	15,532	4,652	23,869	23,044
Planning Area L_2	223	865	236	2,939	532	4,795	4,572
Planning Area N_2	10	133	403	6,699	819	8,064	8,054
Planning Area P	264	8,458	433	1,174	819	11,148	10,884
Planning Area H_1	187	11,266	866	12,380	3,508	28,207	28,020
Los Altos Disposal Service Area	684	20,722	1,938	23,192	5,678	52,214	51,530
Planning Area S	891	4,107	362	968	106	6,434	5,543
Planning Area A_2	480	13,983	2,660	38,493	10,799	66,415	65,935
Planning Area R_2	-	-	-	-	-	-	
Planning Area B	1,224	798	489	1,695	1,044	5,160	3,936
Planning Area C	312	1,062	556	5,649	1,960	9,539	9,227
Planning Area H_2	51	2,540	387	4,083	177	7,238	7,187
Planning Area J_2	6	0	26	190	60	282	276
Planning Area G	31	955	57	881	1,921	3,845	3,814
Planning Area D	523	1,097	295	730	298	7,943	7,420
Planning Area E	503	1,245	43	519	179	2,489	1,986
San Jose Disposal Service Area	4,021	25,697	4,875	56,208	16,544	109,345	105,324
Remainder of County (Planning Areas T, U, Y)	2,200	0	200	2,001	0	4,400	2,200
Total County	9,689	87,100	11,300	153,000	40,400	303,488	293,800

Source: Table 24.

TABLE 24

SUMMARY OF INFORMATION FROM QUESTIONNAIRE

Disposal Site	Total Area acres	Area Remaining acres	Average Depth of Fill feet	Average Lift Height feet	Cover Thickness feet	Source of Cover Material	Reported Refuse Received tons/yr	Composition of Waste, %				Labor Employed, Full-Time Equivalent	Equipment Employed at Site		
								Residential	Commercial and Industrial	Public Trash	Demolition		No.	Type	hr/day
Palo Alto Municipal Disposal Site	-	170	18	18	2	On Site + Public Del's.	50,000	60	25	14	1	6.0	1 1 1 1	Dozer Mich Ldr 8 yd Carryall Pickup	- - - -
Mountain View Disposal Site	30	21	15	-	4	On Site + Purchased Fill	32,000	45	5	50		1.2	1 1	HD 16 TD 15 Dragline	6 1 1
Sunnyvale City Disposal Site	-	-	28	28	2	On Site	76,758	35	65			2.0	1 1 1 1	D 7 D 9 Dragline Shpsft	6 8 8 -
Morgan Hill Disposal Site	50	44	10	4	1 to 2	On Site	3,900	70	30			0.2	1	Dozer	2
Gilroy Disposal Site	100	95	12	5	-	On Site	3,640	70	30			0.4	1	Dozer	-
Pacheco Pass Disposal Site	75	71	20	10	0.5	On Site	3,900	70	30			0.4	1	Dozer	4
Guadalupe Disposal Site	26	a	a	-	-	On Site	135,000	33	23		44	3.0	2 1 1	D 8 Carryall Grader	15 - -
Los Altos Ranch Disposal Site	114	80	20	-	3	-	108,000	80	20			3.0	2 1	Dozer Dragline	- -
City of Santa Clara Disposal Grounds	73	69.6	12	-	2	On Site	24,000	20	80			4.0	1 1 1	D 9 16 yd Carryall Compactor	7 4 6
Newby Island Disposal Site	342	292	28	-	3	-	156,000	75	25			3.5	2 1 2 1	Dozer Grader Dragline Water Wagon	- - - -
Eastside Site		10	25	-	-	-	34,000	-	-	-	-	-	-	-	-
Customer Utility Service Site		3	25	18	-	-	19,500		100			1	2	D 8	-

[a] This is a canyon site. It is filled to 80 feet now. A survey would be required to obtain any meaningful information on remaining capacity.

TABLE 25

DISPOSAL SITE OPERATING COSTS - IMPUTED AND REPORTED

Site	Reported Waste Handled tons/year	Reported Full-Time Employees	Imputed Costs								Reported Costs	
			Estimated Wages & Salaries per month	Estimated Total Cost Labor/year (Cols. 2x3) x 12	Reported Equipment Used	Reported Hours per day of Equip.	Estimated Rental Charge/hr	Estimated Equip. Cost per year (Cols. 6x7) x (260)	Total Cost Col. 4 + Col. 8	Total Cost per ton Col. 9 ÷ Col. 1	Total Cost	Total Cost per ton Col. 11 ÷ Col. 1
(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Palo Alto City Site	50,000	6	$650	$46,800	8 yd Carryall	4	$14.50					
					D-8	6	17.00					
					Mich. Dozer	6	16.00					
		Totals		46,800				66,560	$113.360	$2.26	$112,358	$2.24
Mountain View City Site	32,800	1.2	650	10,920	HD-16	6	16.50	25,740				
					TD-15	1/2	14.50	1,924				
					Dragline	1-1/2	23.50	9,152				
		Totals		10,920				36,816	47,736	1.46	32,340	1.26
Sunnyvale City Site	76,758	2	650	15,600	D-7	6	14.50	22,620				
					D-9	8	20.00	41,600				
					Dragline	8	23.50	48,800				
					Sheepsfoot		$15/day	3,900				
		Totals		15,600				116,920	132,520	1.73	--	--
Morgan Hill Site	3,900	.2	650	1,560	D-6	2	12.50	6,500				
		Totals		1,560				6,500	8,060	2.07	9,100	2.33
Gilroy-Pacheco Pass Sites	8,000	.8	650	6,240	D-8	4	17.00	17,680				
		Totals		6,240				17,680	23,920	2.99	21,060	2.63
Guadalupe Site	135,000	3	650	23,400	D-8	7	17.00	30,940				
					D-8	8	17.00	35,360				
					Carryall	2	14.50	7,540				
					Grader	2	12.50	6,500				
		Totals		23,400				80,340	103,740	0.77	--	--
Los Altos Ranch	108,000	3	650	23,400	D-8	8	17.00	35,360				
					TD-14	8	14.50	30,160				
					Dragline	6	23.50	36,660				
		Totals		23,400				102,180	125,580	1.16	--	--
Santa Clara City Site	24,000	4	650	31,200	D-9	7	20.00	36,400				
					Compactor	6	14.50	22,620				
					16 yd scraper	4	20.00	20,800				
		Totals		31,200				79,820	111,020	4.63	--	--
Newby Island Site	156,000	3.5	650	27,300	D-8	8	17.00	35,360				
					TD-14	8	14.50	30,160				
					2 Draglines	12	23.50	73,320				
					Grader	6	12.50	19,500				
		Totals		27,300				158,340	185,640	1.19	130,000	0.74
County Totals	586,458	23.7	650	186,420				665,156	851,576	1.45		1.22

Sources: Columns 1, 2, 5, 6, 11: were obtained from the site operators.
Column 3: is an average from those site operators who responded to this question.
Column 7: figure obtained from construction equipment rental company.

TABLE 26

ESTIMATES OF SOLID WASTES BY BROAD CATEGORIES IN
SANTA CLARA COUNTY, 1965

Disposal Service Area	Population Average 1964-65	Total Employment Excluding Agriculture	Disposal Site	Classification[a]	Tons					
					Total Refuse Received (Excluding Agr. Wastes)	Household Rubbish & Garbage	Commercial & Industrial Rubbish	Cannery[b] Waste	Public Trash	Demolition Waste
Palo Alto	66,847	41,194	Palo Alto Municipal Site	S	50,000	32,000	10,500		7,000	500
Mountain View	47,412	26,754	Mountain View Site	S	39,800	14,760	1,640		23,400	
			Stierlin Road Site	P	27,000				27,000	
Sunnyvale	85,545	38,673	Sunnyvale City Disp. Site	S	76,758	26,865	49,893			
Gilroy-Morgan Hill	32,960	5,100	Gilroy Disposal Site	S	3,640	2,548	1,090			
			Pacheco Pass Disposal Site	S	3,900	2,730	1,170			
			Morgan Hill Disposal Site	S	3,900	2,730	1,170			
			San Martin Disposal Site	P	7,000				-----7,000----	
			Furtado Ranch	C						
Los Gatos	151,225	23,044	Guadalupe Site	S	155,050	------44,550-----			----90,500----	
			Pierce Ranch	C	1,595			1,595		
Los Altos	133,200	51,550	Los Altos Ranch Disp. Site	S	108,000	86,400	20,500	1,100		
			City of Santa Clara Site	S	24,000	4,800	19,200			
			Edgewater Site	P	37,000				37,000	
			Woelfel Ranch	C	114			114		
San Jose	354,325	105,304	Newby Island Site	S	156,000	117,000	39,000			
			Eastside Site	S	54,000					
			Customer Utility Site	S	19,500		19,500			
			Storey Road Site	P	37,000				37,000	
			City of San Jose	P	55,000				55,000	
			Singleton Road	P	17,000				17,000	
			Theur Ranch	C	1,215			1,215		
			Hessler Ranch	C	6,460			6,460		
			Collier Charcoal	C	410			410		
			Silviera Ranch	C						
			Carroll Ranch	C	5,560			5,560		
Remainder of County	3,091	2,200			-	-	-	-	-	-
County Total	874,599	293,799			870,670	-----498,568-----		14,204	---304,400----	

Disposal Service Area	Tons				
	Agricultural Manures[c] (Dry)	Agricultural Prunings[c]	Sewage Sludge[c] (Dry)	Junked Vehicles[e]	Total Wastes
Palo Alto	255				
Mountain View	8,900				
Sunnyvale	59				
Gilroy-Morgan Hill	18,530				
Los Gatos	1,595				
Los Altos	941				
San Jose	4,099				
Remainder of County	7,237				
County Total	39,548[d]	75,000[d]	3,860[e]	24,500[f]	1,011,580

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[a] The symbols refer to the following: S - Sites that are primarily served by scavenger companies.
P - Public trash sites used by the general public and incidental haulers only.
C - Cannery waste disposal grounds.

[b] Cannery waste data are for 1965 which was an unusually short season.

[c] Rows refer only to area in which waste is generated, not to area in which they are disposed of.

[d] The sources are the following reports: California Department of Agriculture, State Agriculture Report, 1965; University of California Agricultural Extension Service of California Air Pollution Research, Progress Report: Disposal of Agricultural Wastes in the Bay Area, July 1966; and Agricultural Commissioner's Crop Report, 1965, Santa Clara County.

[e] The source is the ABAG figure for the Bay Area, using population to determine Santa Clara County's share.

[f] The source is the Department of Motor Vehicle reports showing age distribution of motor vehicles. The number of junks was determined by calculating the number of older vehicles that disappeared between 1964 and 1965 distributions. This number of junks was multiplied by 1.75 tons.

serious lack of detail, the solid wastes totals were treated as a single dependent variable in the regression study. They were regressed against possible explanatory variables such as population, employment in manufacturing, employment in nonmanufacturing, land use in manufacturing, and land use in nonmanufacturing. According to the regression study, population is a significant variable, and it explains most of the variation in the generation of solid waste. Land in nonmanufacturing sectors (service sectors) constitute the second important variable. Since the number of observations (seven) is very small and the number of variables almost outweigh the degree of freedom, any further use of regression equations in this case is not applicable.

The data use in the regression model are given in Table 27. The regression equations are given in Table 28.

The regression models explain the variation in solid waste generated vis-a-vis the independent variables — population, employment, and land use. Such models could also be used for developing projections of waste based on projections of population, employment, and land use simply by using the projected values on the right hand side of the structural equations.

DATA COLLECTION PLANS

Information gained in the pilot study was used in formulating data collection plans. As is evident in the previous description and discussion, the data on solid wastes must be collected in more detail than was possible in this study if they are to be of use in establishing an analytical framework. Moreover, data on other related economic variables need to be collected and compiled for analysis through the use of computers. For the sake of convenience and as a means of organizing present and future data needs, a detailed listing of data items was prepared in consultation with the Computer Center of the University of California for eventual compilation. The various data items to be collected and corresponding coding are described in Appendix F. The listing makes it possible to transfer raw data to a punch card system after careful editing. With the data on punch cards, it is possible to conduct further analytical operations directly on the IBM computer. This arrangement will provide the necessary empirical base for analyzing the solid waste management problems with respect to the objectives listed and discussed earlier.

TABLE 27

DATA USED FOR REGRESSION ANALYSIS
SANTA CLARA COUNTY

Disposal Service Area	Solid Waste Generated (tons)	Population	Employment, Manufacturing	Employment, Non-Manufacturing	Land Use, Manufacturing (acres)	Land Use, Non-Manufacturing (acres)
Palo Alto	50,000	66,847	11,278	29,916	362	2,270
Mountain View	59,800	47,412	4,997	21,737	175	696
Sunnyvale	76,758	85,545	21,280	17,393	798	2,086
Gilroy-Morgan Hill	13,440	22,950	1,800	3,300	115	587
Los Gatos	136,415	151,225	1,326	21,718	52	1,483
Los Altos	189,114	163,200	20,722	30,808	806	1,773
San Jose	345,145	334,325	25,697	77,627	1,427	5,323

TABLE 28

SANTA CLARA COUNTY WASTE GENERATION, SUMMARY
OF LINEAR REGRESSION RESULTS

Y: Dependent Variable	Constant Term	X_1: Population Coefficient	X_2: Employment, Manufacturing Coefficient	X_3: Employment, Non-Manufacturing Coefficient	X_4: Land Use, Manufacturing Coefficient	X_5: Land Use, Non-Manufacturing Coefficient	$R^2_{y \cdot x}$
Waste Generated, tons							
Step 1	-7887.77051	1.06240^a $(0.06334)^b$					0.98254
Step 2	-20648.77905	1.04240^a $(0.06643)^b$				0.30379 $(0.30403)^b$	0.98603

[a] Significant t-ratio at 99 percent confidence.

[b] Figures in parenthesis represent the standard error of the corresponding coefficient.

V. PUBLIC HEALTH

INTRODUCTION

As noted in a previous section (Figure 2, page 12) one of the four major aspects to which research teams have directed attention during the period herein reported (1966-67) is Public Health. In the overall regional waste generation and evaluation model (Figure 9, page 39) which describes the study, Public Health appears as one of the important subsystems, imposing constraints specifically upon such other subsystems as Land Use and Technology and directly upon the final Waste Collection and Disposal Model which describes the management scheme for any individual regional situation. Thus, within this conceptual framework it is necessary to consider the nature of public health constraints with regard to several factors.

1. The extent to which they are qualitative or quantitative in nature.
2. The effect of qualitative constraints on the numerical values necessary to make the affected subsystem model functional and capable of resolution.
3. The public health justification of assigning specific numerical values to its quantitative constraints.

In simpler terms this means that on the basis of present knowledge, and the results of definitive research, or by subjective reasoning based on judgment and man's social objectives, the public health aspect of the study must yield numerical limits on what waste management procedures may contribute to the air, water, and land environments.

OBJECTIVES OF PUBLIC HEALTH RESEARCH

The foregoing interrelationships between the public health model and other models or subsystems depicted in Figure 9 makes possible a clear statement of the objectives of the public health aspect of the study. These include:

1. Evaluating the true relationship between solid wastes management procedures and health dangers to the public.
2. Reviewing critically all public health regulations relating to solid wastes management with particular reference to the source and validity of any numerical values imposed.
3. Advising all other research teams of the known or possible health implications of their alternate proposals for wastes management.
4. Considering the components of solid wastes and the environmental fate of each in wastes disposal, with particular reference to the health and welfare of humans.
5. Conducting definitive research on such of the components of solid wastes which are judged likely to have a significant effect on human health or welfare.
6. Evaluating the occupational hazards to workers in the solid wastes management field.

Progress toward each of these objectives is herein reported.

RELATIONSHIP OF WASTES MANAGEMENT TO HEALTH

Although it is at once evident that there is a public health interest in the management of any material which may produce flies, mosquitos, rodents, or other vectors of disease, the role of public health in solid wastes research is not so obvious. Good housekeeping in such matters as household handling of garbage, use of tight containers, frequent and tidy collection, and provision of proper collection vehicles controls the generation of vectors in the general environment where domestic refuse is produced. Landfill practices in refuse disposal eliminate insect and rodent problems on any scale compared to the potential of refuse to produce them. But here again, good housekeeping minimizes dust, odors, blow-about, and other aesthetically objectionable factors. Incineration of refuse as a problem in itself tends to be overwhelmed by the greater problem of air pollution by other combustion processes. Animal manures, with their vast potential to produce flies, require insect control programs and physical removal from the immediate environment of people. Demolition debris is generally innocuous, as are tree and grass trimmings and junk. Composting is not yet commercially important, and hog feeding with garbage is a declining practice.

From such gross observations as the foregoing it might be concluded that the major unsolved problems of solid wastes management are not those of public health, and that a combination of vigilance and good housekeeping, together with concern for the accident and other health hazards to refuse handlers, essentially defines the area of public health concern in the problem. To an important degree such a conclusion is valid at present. However, for the immediate and longer range future there are at least two factors which suggest a closer look at the role of health research in a solid wastes management research program.

1. The problem of solid wastes management is far from resolved, hence it may not be assumed that any resolution will leave undisturbed any existing equilibrium between refuse management and health objectives.

2. Public health concern in the modern world transcends traditional concepts of vectors and nuisance.

Each of these is worthy of further explanation. Possible sources of health problems may be found in both the changing content of refuse, and in technological possibilities of the future. An analysis of these possibilities based on the feasible methods of management outlined in Figure 1 (page 8) is summarized in Table 29. In this table the solid wastes of an overall community are depicted as a "waste stream" moving from the source to some "sink," which for the most part is the land resource. In some of the five cases noted, a fraction of the stream is split off, processed, and recycled to the industrial resource with residues returned to the land or atmosphere.

As indicated in Table 29 public health concern in solid wastes management includes occupational health, public health per se, and general affronts to the senses of sight and smell commonly classed as nuisances. However, there is reason to consider public health in much broader terms.

Within a broad sociological concept of public health there are myriad problems associated with solid wastes. Noise, odors, increased traffic, contention over ownership of cans, requirements for household management of wastes, littering of the neighborhood, and similar factors add stress to life which is not subject to the type of definitive research which contributes to technological solutions to the problems of wastes management. Nevertheless, such qualitative considerations may exert a profound effect on technology, land use, and the final collection and disposal models of the system (Figure 9), through simple refusal of the public to accept answers proposed by its engineers and other officials. Examples of such constraints are to be found in the San Francisco Bay area in the rebellion of citizens of the town of Brisbane against the landfill operations of the city of San Francisco despite contractual relations made by their officials and the long standing practice of

TABLE 29

POSSIBLE HEALTH PROBLEMS IN SOLID WASTES MANAGEMENT

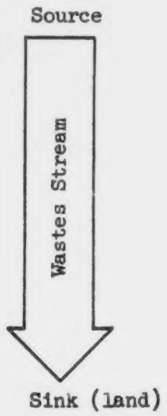
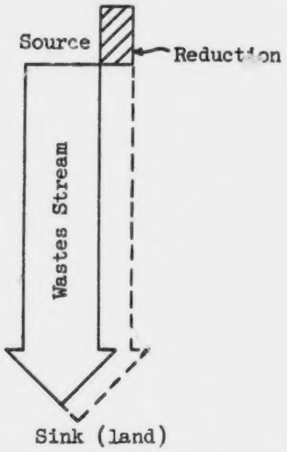
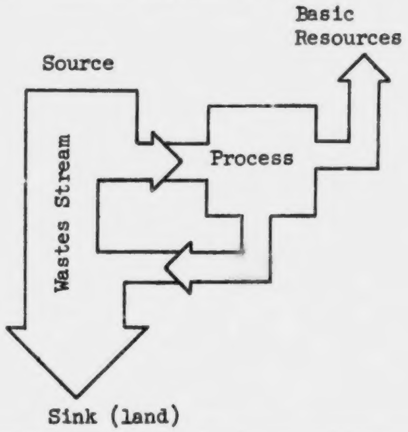
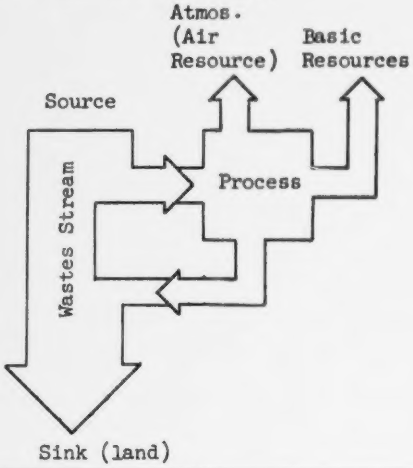
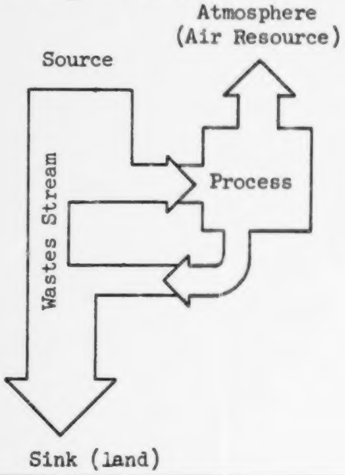
Method	Nature of Possible Health Hazard
Case 1. Disposal to sink.  Source Wastes Stream Sink (land)	1. Occupational hazard to workers in collecting, transporting, and land disposal. 2. Public health and nuisance hazard associated with poor operation of fill, e.g., vectors, blow-about of paper, etc. 3. Nuisance hazard due to careless or neglect of fill, e.g., odors and gases from burning fill. Vectors and odors if fill becomes fractured. 4. Public health hazard or nuisance from ground water contamination by leachings or gases from fill.
Case 2. Reduction in volume at source.  Source Reduction Wastes Stream Sink (land)	1, 2, 3, 4. Same as Case 1. 5. Occupational hazard to workers involved in activities which reduce volume of wastes; principally industrial hazards not unique to wastes per se.
Case 3. Direct recycling.  Basic Resources Source Process Wastes Stream Sink (land)	1, 2, 3, 4. Same as Case 1. 5. Occupational hazard to workers in process (principally salvage). 6. Occupational hazard to workers utilizing salvaged material returned to resource.

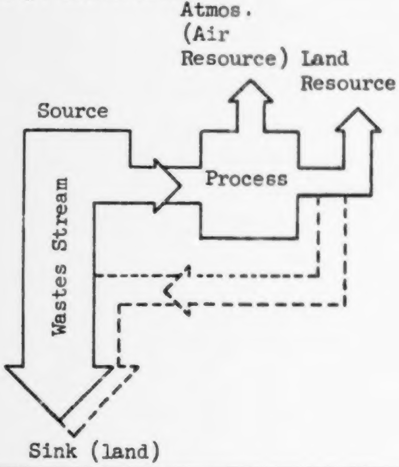
TABLE 29. Continued.

<table>
<tr>
<td>Case 3. Indirect recycling.


Atmos.
(Air
Resource)
Basic
Resources
Source
Process
Wastes Stream
Sink (land)

</td>
<td>1, 2, 3, 4. Same as Case 1.
5. Public health hazard in products discharged to atmosphere.
6. Occupational hazard to workers in processes such as rendering, pyrolization, grinding of glass, etc.
7. Occupational hazard to workers utilizing processed material returned to resource.</td>
</tr>
<tr>
<td>Case 4. Change of state.


Atmosphere
(Air Resource)
Source
Process
Wastes Stream
Sink (land)

</td>
<td>1, 2, 3, 4. Same as Case 1.
5. Occupational hazard to workers in process (principally incineration).
6. Nuisance in process residues, e.g., fly-ash dust.
7. Public health hazard in process discharge to atmosphere.
8. Nuisance in process discharge to atmosphere.</td>
</tr>
<tr>
<td>Case 5. Conversion.


Atmos.
(Air
Resource)
Land
Resource
Source
Process
Wastes Stream
Sink (land)

</td>
<td>1, 2, 3. Same as Case 1.
4. Occupational hazard in process (principally composting).
5. Nuisance in process discharged to atmosphere, e.g., odors.
6. Public health hazard to users of processed material, e.g. virus.
7. Occupational hazard in handling processed material.</td>
</tr>
</table>

landfilling by the city. Similarly, public sentiment against the long accepted practice of utilizing marginal areas of the San Francisco Bay for refuse landfills threatens to terminate the practice without regard to alternatives. Since the environmental objectives of people are a real factor in practical solid wastes management they must be considered by some group engaged in the study herein reported; and the public health team was deemed to be the most logical choice.

In the investigation herein reported, public health is interpreted as including virtually all aspects of solid wastes management in which man is the center of concern. Thus if solid wastes adversely affect people physiologically or psychologically, or make the environment less comfortable or less pleasant by affronts to any of the five senses, it is interpreted as being of public health concern. Obviously, this interest in man is not confined exclusively to the public health model of Figure 9. The land use, population, process technology, and economic models, and to a lesser degree other components of the regional waste generation and evaluation model (Figure 9), all involve the interactions of environment and man as well as man's response to constraints. This, however, is fortunate in that it insures a constant interplay between the several research teams and minimizes the problem of maintaining coordination between them.

Pursuant to objectives 1, 2, and 3 (page 75), progess has thus been made by the public health research team during the period reported. Work along these lines, however, is a continuing activity subject to continual refinement as:

1. Studies by cooperating agencies (U. S. Public Health Service and California State Health Department) and by the technological teams provide greater detail concerning the amount and nature of individual components of refuse.

2. Proposals for improved or new technology are generated by the various research teams in this area.

3. Further review is made of the literature and of other reports associating solid wastes with any aspect of public health.

4. Public reaction to proposed solutions develops.

RELATION OF WASTES COMPONENTS TO HEALTH

Objectives number 4, 5, and 6 (page 75) of the public health research team relate to consideration and definitive research on the ways in which the possible public health hazards listed in Table 29 may affect the health or welfare of the public in general or of workers in the wastes management field. Two principal avenues of investigation are evident.

1. A determination of the health significance of wastes component materials.

2. The environmental fate of fractions of refuse known or judged to have significant health implications.

A specific example of the first of these two might be found in the discharge of lead ions into the atmosphere as a result of burning automobile storage battery cases or salvaging of lead. Since lead is known to be inimical to health, it might be suspected that a significant problem exists. However, when the contribution of lead through the use of leaded gasoline is considered, the added contribution from wastes management schemes is almost certainly trivial on a macroenvironmental scale either to an appreciable number of citizens or to salvage workers. Nevertheless, since the extent of this contribution is not know, investigative work may be in order.

Examples of the second type of question exist perhaps in the ultimate fate of such materials as asbestos fibers, beryllium, radioisotopes, microbes, viruses, etc. in various waste disposal procedures in relation to human contact. Emissions from incinerator stacks, leaching from landfills, and fertilizers from sewage sludge digestion or composting processes are among the avenues by which materials of signficance to public health might adversely affect man.

Against such a rationale the public health research team initiated during 1966-67 investigations relating both to what materials and in what concentrations they follow these various avenues. As in the case of work directed to the first three objectives (page 75) such investigations depend for their increasing productivity upon the development of greater detailed knowledge of the components of community-wide refuse, and to a lesser degree upon solutions to disposal problems offered by the technological research teams. Initial concern, however, has been directed to processes in common practice and to factors known to be produced from refuse by these processes. Results thus far obtained are laregly derived from the literature. They relate to the possible health effect on citizens or on workers in the industry of agricultural and industrial wastes and of disposal methods.

Agricultural Wastes

Little experience is reported with the disposal of agricultural wastes in combination with other wastes of an urban-industrial-rural community. As noted in a previous section the rural sector has been generally expected to look after its own wastes in a manner acceptable to its urban neighbor and then only as regards the generation of odors, dust, flies, mosquitoes, and rodents. Sharing the general attitude of citizens toward waste materials, and having in addition a weaker economic base for which to operate, agriculture has utilized only the most primitive methods of disposal, i.e., burning, discharge to water, and disposal on the land surface either by spreading or placing in open piles. Therefore the potential of agricultural wastes to produce health problems, rather than demonstrated effects, is the basis for judgment.

Of greatest concern in the agricultural wastes area is the production of flies by animal manures which, although possibly only a nuisance, always constitutes a danger to the public health. In California, for example, a single installation may fatten 3,000 to 6,000 steers per year or maintain 10,000 to 100,000 hens. These and close-in dairies are estimated to produce 20 million cubic yards of animal manures annually at the zone of contact between California's urban and rural sectors.

Other than manures, by far the biggest fraction of agricultural wastes are crop residues which represent the normal type of photosynthetics produced by nature and has little direct implication for the public health.

Many of the agricultural wastes, however, especially those from highly concentrated operations such as hen and egg production and feedlots, contain elements which if allowed to leach into ground or surface waters might constitute a localized concern to public health via water contamination. Examples of these are As, Mn, and Zn substances which are normally found in poultry manure. The danger resulting from runoff from feedlots is in the large amount of organic and ammonia-N content of the runoff waters. This nitrogen is oxidized to NO_3 in the soil and as such is responsible for excessively high NO_3 levels in waters thus contaminated. Another factor that may be of public health concern is the practice of burning agricultural crop wastes. The resulting air pollution may be of some public health significance in already polluted areas. Another waste associated with agricultural practice consists of emptied pesticide containers. Unless carefully disposed of, they pose a threat by way of indiscriminate reuse for other purposes and by accessibility to children and animals.

Industrial Wastes

The research schedule of the study herein reported calls for the obtaining of detailed data on the composition of industrial wastes in a pilot area of California from other state and federal agencies supported by demostration grants from the Public Health Service. The data, which should be available late in 1967, will then become the basis for an evaluation and possibly definitive research activity by the University of California public health research team. In the meantime, this team in 1966 made an independent survey of industrial operations in a selected region in the Bay area, viz., Santa Clara County, as a part of an attempt to determine the extent of any threat to public health to be found in wastes generated by these industries. Of 28 industrial operations active in the county, all but three generate wastes which have metals, wood, and paper as components. The wastes of all but four have fibers, synthetic, plastic, and natural. Almost half of the total industrial waste output contains organic and inorganic chemicals of some sort: petroleum, paint, glass, ceramics, and minerals. Inasmuch as at the time of this survey information was unavailable as to the disposition of the wastes from these sources, no estimates of the actual threat to the public health posed by these wastes could be made. As in the case of agricultural residues, municipal refuse disposal has not traditionally been concerned with industrial wastes but has left to the industry the problem of disposal. Public regulation of waste disposal, however, has attempted to exclude from landfills such materials as oils, solvents, and chemicals — not always with success. Most certainly there is a potential threat to the public health in many chemicals which might reach the groundwater via discarding in sanitary landfills.

Methods of Disposal

Because disposal technology is a key element in solid wastes management, and no foreseeable technology can remove wastes from some combination of the air, water, and land resources, the public health implications of wastes disposal are worthy of very close scrutiny. Moreover, where health hazards are a factor ways must be found to preclude contact between man and the hazardous components of his refuse. Unfortunately the hazards of many fractions of refuse have not been explored.

For example, the contribution of refuse incineration to air pollution has generally been recognized, perhaps to an exaggerated degree when considered in relation to the total air pollution coming from other sources of burning. On the other hand, concern has been expressed largely for the oxides of sulfur and nitrogen, carbon monoxide, and visible particulates — residues which may not be the critical discharges from burning of mixed solid wastes. Thus that aspect of incineration which is not so conspicuous and which is now being studied is the fate of some of the more exotic materials in refuse and of the solid residues. Similarly, the superficial aspects of landfill have always received much attention, while less obvious but perhaps more important aspects have only relatively recently become a matter of concern. Thus, appearance and odors associated with landfills are by their nature conspicuous characteristics, whereas leaching and gas migration are subsurface phenomena, and hence inconspicuous as far as the casual observer is concerned. Composting, while not commonly practiced at present, nevertheless merits attention, since it is frequently advocated as the ideal disposal method, especially from the standpoint of public health. Despite the high temperatures and other conditions unfavorable to pathogenic organisms, composting also has some characteristics which may pose a health hazard. Among these might be mentioned the presence of pathogenic fungi. From these examples it is evident that much research needs to be done before the public health constraints on other elements of the waste generation and evaluation model can be given realistic values.

Incineration. The by-products of incineration are a volatilized moiety and a residue, both of which have implications for public health. Analyses of the effluent gaseous material and leftover inert residue reveal that their composition varies directly in relation to that which is fed into the incinerator. Unfortunately, until the present, studies concerned with the composition of solid waste material introduced into municipal or other incinerators have been very few.

Effluents generated by the burning of refuse can be broadly categorized as inorganic and organic gases and particulate matter. Although not all of the constituents of the gaseous effluents have been identified or analyzed, the principal inorganic compounds have been classified as H_2S, SO_2, S_2O_3, nitrogen oxides,

NH_4, CO, and CO_2. Prominent organic constituents are aldehydes (formaldehyde and acrolein), organic acids and esters, fats and fatty materials, phenols, and polynuclear hydrocarbons. Particulate matter consists of smoke, soot, fly-ash, grit, and dirt. An idea of the composition of the stack discharge can be obtained from a perusal of the data list in Table 30.

Even prior to identification, the inorganic gases make their presence evident by minor irritant action on skin and mucous membranes or by their odor. Oxides of sulfur are highly irritating to the upper respiratory tract when inhaled, and can cause serious trouble in susceptible individuals. As is to be expected, the effluents are clearly related to the sulfur content of the input to incinerators, which is not usually excessive. Generally, however, the concentration of SO_2 in the stack gases of incinerators is in trace quantities, not exceeding the range of 1 to 20 mg/ℓ. Nitrogen oxides are insidous gases which may bring about long-term damage to the lung and bronchial passages, even though they do not cause any immediate physiological difficulties. The compounds NH_4 and $(NH_4)_2SO_4$ are of concern in areas of heavy pollution. They may be present in incinerator gases in concentrations ranging from 0.5 to 10.0 mg/ℓ.

Carbon monoxide and dioxide make up the bulk of the remainder of the incinerator gases of concern to public health. Carbon monoxide is a colorless and odorless gas which readily combines with hemoglobin. This latter reaction may bring about asphyxiation because of interference with the circulatory transport of oxygen in an individual. Studies recently conducted at Stanford University and at other research centers indicate, however, that long before such a chemical asphyxiation supervenes, behavioral changes such as mental confusion will be noted, electroencephalogram patterns will be altered, etc. These adverse reactions definitely indicate an interference with optimal human function caused by carbon monoxide toxicity. Carbon dioxide also can lead to serious ill effects if the concentration exceeds one percent of ambient air. The role of these regular by-products of incineration has not been fully explored, probably because atmospheric dilution has prevented a buildup of concentrations to levels detrimental to public health. The more subtle effects certainly warrant more well-planned investigations; and, therefore, not only their immediate effects, but the concomitants of continuous, long-term inhalation in small amounts need attention.

The incineration of the organic matter in refuse results in the generation of a wide variety of effluent gases. Although a satisfactory analysis of these gaseous effluents of organic origin is yet to be made, certain compounds suggest themselves. These are the aldehydes such as formaldehyde and acrolein, both pungent in odor and highly irritating to eyes and skin as well as to the mucous membranes. Acrolein, which was even used as a poison gas in World War I, can be readily formed by burning fats and oils. The combustion of these latter substances also results in the formation of various organic acids and esters. Certain phenols and phenolic substances liberated during combustion can harm tissues if present in a sufficiently heavy concentration.

Another class of organic compounds significant in extent of disease transmitting potential is that of the polynuclear hydrocarbons. While it is known that a great many of these hydrocarbons are formed, their exact amounts are unknown at present. Many of them are known to be carcinogenic, and as such should be carefully assessed and monitored.

The particulates, found in all kinds and sizes in incinerator stack discharges, have physiologic and pathologic significance inasmuch as they are often impregnated with acids and are filtered out by lung tissue. Upon lodging in the lungs, they can lead to the development of a focal buildup. All organic fractions of airborne particles sampled from the atmosphere in U. S. cities have been shown to be capable of producing local skin tumors in mice following subcutaneous infection. Chronic low level exposure seems to be more injurious than brief heavy exposure.

A further deleterious development in the gaseous environment has to do with interactions between the different gases at concentrations lower than those required

TABLE 30

AIR POLLUTANT EMISSIONS FROM SOLID WASTE DISPOSAL[a] [13]
(expressed in tons/yr)

Category	Aldehydes	CO	Hydrocarbons	N-Oxides	S-Oxides	Particulates	B(a)p [b]
Incinerator (Total)	150	377	396	323	226	1,486	14
Municipal	39	33	33	268	201	1,004	3
Residential	25	na [c]	19	25	25	80	na [c]
Industrial	52	208	208	17	na [c]	262	6
Other	34	136	136	13	n [d]	140	5
Open Burning (Total)	1,140	na [c]	84,300	165	297	14,147	402
On-Site	572	na [c]	44,500	80	127	7,473	245
Dumps	568	na [c]	39,800	85	170	6,674	157
Total	1,290	377	84,696	488	523	15,633	416
Other Sources (Auto Exhaust, etc.)	1,800	1,088,000	235,000	48,000	4,400	7,100	489

[a] From an area of 3,567 sq. miles including St. Louis and six surrounding counties.

[b] Benzo(a)pyrene in lb/yr.

[c] na = information not available.

[d] n = negligible.

to cause any overt effect on health. These are the reactant mixtures involved in what is known as photochemical smog, a type which is prevalent in Los Angeles and other heavily populated and industrialized areas. At their lower levels of concentration, ozone and compounds of nitrogen formed through oxidation results in eye and nasal irritation; while at higher levels, they bring about serious derangement of lung and cerebal function. Although it is well established that the internal combustion engine is the main source of hydrocarbons involved in photochemical reactions, not to be ignored is the contribution of gases from inadequately burned refuse in household and municipal incinerators, the extent of which is as yet undetermined. Some idea of the relative amounts from the two sources may be gained from the data listed in Table 31, in which are given estimates of contaminants poured into air in Los Angeles County; and from Table 32, in which the data are given on pollutants discharged in the St. Louis area.

TABLE 31

TONS OF CONTAMINANTS INTRODUCED
INTO LOS ANGELES COUNTY ATMOSPHERE, 1962 [44]

Source	Hydrocarbons and Organic Gases	Oxides of Nitrogen	Oxides of Sulfur	CO	Other Inorganic Gases	Aerosols
Stationary	4	4	1	4	n	4
Total	740	220	105	235	5	5

In situations in which there is a recurrent photochemical smog situation, undoubtedly all incinerator operations could be a source of danger.

Air pollution control codes adopted in many areas are not sufficiently based on careful measurement or on up-to-date information as to the health effects of combined exposures. Synergism and augmentation through concatenation of mild irritants and photochemical reactions in the atmosphere need to be taken into account. Additionally, the meteorological status very often determines what is allowable at a single point of time. Local codes, on the other hand, often are based on general findings of maximum allowable concentrations of single chemical entities worked out in a restricted occupational environment in which exposure is not continuous and where it can be easily controlled. Our present understanding of the mode of action of environmental toxic compounds goes too far beyond such initial guide lines to permit the assumption of a comfortable posture in regard to the air pollution standards.

Noncombustibles in refuse undergo oxidation to varying degrees during incineration, depending upon furnace conditions. Metallic oxides remain as residue or are dissipated in the flue gas. The residue that becomes mixed with the water in the quenching operation poses a problem in disposal. Among the metals which have been identified in incinerator ash and which could pose a public health hazard are: Co, Pb, Zn, Cu, Cd, Fe, Cr, Mn, Ni, and As. Arsenic is dangerous even in trace amounts if allowed to leach into surface waters, since fish concentrate the element in their tissue. The concentrated inorganic fraction of the solid wastes consists of soluble and insoluble salts of various heavy metals that can leach into ground water, and thus lead to the development of brackishness and the accumulation of other undesirable contaminants in the water. Vaporized metallic oxides having been expelled into the atmosphere eventually settle on the land where they are introduced into living systems through inhalation and ingestion. This has been demonstrated to be the case with cadmium [45, 46]. The concentration level of which is significantly higher in urban areas than in nonurban nonindustrial environments. A correlation has been established between a cadmium buildup in the kidney tissue of higher mammals and an increased incidence in hypertension and heart disease.

TABLE 32

SUMMARY OF AIR POLLUTANT EMISSIONS
IN ST. LOUIS AREA STUDY, 1963 (tons/yr) [13]

Category	Aldehydes	CO	Hydrocarbons	Nitrogen Oxides	Sulfur Oxides	Particulates	B(a)p [a]
Transportation	1,800	1,088,000	235,000	48,000	4,400	7,100	489
Stationary	600	26,300	6,200	85,000	421,000	86,400	641
Refuse Disposal	1,300	400	84,700	500	500	15,600	416
Incineration	150	400	400	300	200	1,500	15
Open Burning	1,150	--	84,300	200	300	37,500	451
Industrial Processes	--	--	11,700	4,200	29,600	37,500	--
Solvent Evaporation	--	--	36,000	--	--	--	--

[a] Benzo(a)pyrene.

At least one investigator in this country has related the steep increase in cardiovascular disorders with the deposition of cadmium and other trace metals in organs of the body [45].

Investigators have found that tissues of wild rats living in the vicinity of sewers and refuse dumps generally have a much higher lead content than those of rats reared in the laboratory [47]. Associated with this higher lead content is a high degree of incidence of nuclear inclusions and carcinomas in the kidneys of the wild rats. Although it cannot be stated on the basis of the evidence on hand that these inclusions and carcinomas are caused solely by lead, there is good reason for believing that lead may be the precipitating agent. In their paper, Kilham et al. [47] report that the wild rats assayed in their study were continuously exposed to dense smoke emanating from the smoldering refuse in the dump in which the rats lived. They surmised that the lead was oxidized and carried with the smoke. The rats inhaled the lead oxides along with smoke. The authors surmise that the oxidized lead came from the sizing in paper, from paint, solder, batteries, and any other waste which may have contained lead in one form or another.

Studies of incinerator residue conducted at Drexel Institute indicate the existence of pockets of metallic residue buildup in the soil. No explanation for these buildups is available at present. This heavy metal buildup and its public health aspects is an area for further study and surveillance.

Sanitary Landfill. Despite its widespread application, the influence of sanitary landfill on the surrounding environment was not investigated in any great depth until relatively recently. In addition to the usual financial reason for the belated interest in the subject, there may have been the one stemming from man's inborn belief that burial accomplishes removal from the environment. It was only with the intensification of the general concern for all phases of the environment that the practice of landfill and its relation to the environment began to come under close scrutiny. Aside from the purely aesthetic, this influence can be exerted by way of leaching of substances to ground waters or by migration of gases from the disposal site.

Leaching studies have shown that water moving through an unsealed or improperly located landfill will leach soluble salts and alkalies from the dump and transport them to receiving waters. Thus ground water in the immediate vicinity of a landfill site can become grossly polluted by continuous or intermittent contact with deposited refuse. In studies conducted in California by the State Water Pollution Board [48,49] it was demonstrated that within a year after the initiation of one operation, continuous leaching of one acre-foot of the fill being investigated would result in the extraction of 1.5 tons of sodium and potassium, 1.0 ton of calcium and magnesium, 0.91 ton of chloride, 0.23 ton of sulfate, and 3.9 tons of bicarbonate. The amount and rates of extraction become much slower with the passage of time.

In a pilot-scale study involving simulated landfills, Burchinal et al. [50] found the concentrations of leachate to be those listed in Table 33. The water-holding capacity of the refuse used in their study was 1.62 in./ft of refuse. Burchinal et al. point out that although the concentration of leachate from the deeper fills was greater than that from the shallow fill, the maximum concentration per foot of depth of fill for an equal amount of refuse was lower in the deeper fills. Their assessment of the amount of pollutants which would be leached by an equivalent of 0.45 in. of rainfall percolating through one acre-foot of 2.5, 6.5, and 10 ft refuse beds is summarized in Table 34.

Burchinal et al. stress several considerations which seem to be of special importance to them as a result of their investigations. They are:

1. The potential damage to underground reservoirs by way of increase in hardness, in the concentration of iron, nitrogen, and sulfur compounds, and in that of total dissolved solids.

TABLE 33

CONCENTRATION OF LEACHATE FROM SIMULATED LANDFILLS CONTAINED IN CONCRETE CYLINDERS[a]

Item	Cylinder Depth (ft)		
	4	8	12
BOD (5-day)(mg/ℓ)	14,760	26,940	33,360
Alk. (as Ca CaO_3)(mg/ℓ)	10,630	16,200	20,850
$Na^+ + K^+$ (mg/ℓ)	1,634	3,963	5,109
Cl^- (mg/ℓ)	951	2,000	2,310
Total N (mg/ℓ)	613	1,384	2,508
Total Solids (mg/ℓ)	21,140	49,000	59,000

TABLE 34

ESTIMATION OF POLLUTION FROM REFUSE BEDS OF VARIOUS DEPTHS DURING PERCOLATION OF THE EQUIVALENT OF 45 in. of RAINFALL[a]

Item (tons)	Refuse Bed Depth (ft)		
	2.5	6.5	10.0
BOD (5-day)	17.2	14.4	12.3
Bicarbonates	12.8	9.7	8.0
$Na^+ + K^+$	29.9	22.6	19.6
Cl	1.04	0.83	0.8
SO_4	0.68	0.44	0.28
Total N	0.83	0.78	0.78

[a] See Reference [50].

2. A need to know more about dispersion phenomena which occur during the movement of pollutants.

3. The possibility of decrease in permeability.

4. The dilution effect of moving water on the concentration of leachates.

5. The dissolving of minerals and subsequent degradation of water quality brought about by moving a large amount of CO_2 through an aquifer.

A partial answer to the problems posed by Burchinal et al. may be found in the results of other studies in which drops in volatile solids after passage of leachate through 30 ft of soil ranged from 63 to 89 percent, and that of total dissolved solids, from 70 to 91 percent [51]. In another investigation in which the reduction in concentration of a wide range of ions and other materials brought about by passing through 50 ft of soil was determined, drops ranging from 51 percent of the Ca^{++} to 99 percent of the COD were observed. Incidentally, they observed a sharp reduction in threshold odor, about 99.5 percent according to their scale.

Burchinal et al. [50] also investigated the travel of the volatile organic acids in studies with simulated landfills. Of the acids, butyric and valeric were the most signficant in terms of leachate concentration. Caproic, valeric, and propionic acids were in much lower concentrations. Dissociated forms of volatile acids accounted for approximately 75 percent of the total anions in a given leach sampler.

Microorganisms have been found in significant numbers in the leachate from sanitary landfills. From seepage from a fill in West Virginia, Burchinal et al. [50] isolated representatives of nine genera of mesophilic aerobes, two of hermophilic aerobes, two of anaerobes, four of actinomycetes, and 15 of fungi. Eliasson [52] records findings of as high as 975 x 10^6 fungi and 73 x 10^6 bacteria per gram of dry fill after 9 to 18 months and lower — but substantial — numbers in some four-year old undisturbed fills. (Eliasson's findings deal with the fill material itself — not the leachate.) The health significance of this aspect is that if such a rich flora can be found in the leachate from a fill, pathogens buried with the garbage could also be transported out of the fill by way of leaching water.

An important consideration concerned with public health has to do with the emanation of gases from sanitary landfills. These gases represent a portion of the metabolic end products of the many types of microbiological organisms found in the decomposing material in a fill. Gases identified and measured thus far are H_2, N_2, CO_2, CH_4, and H_2S [51]. The composition of the gas produced in the landfill resembles quite closely that produced in the digestion of raw sewage sludge. Eliasson reports the composition of gas produced in a four-year old fill as being 28 percent CO_2, 56 percent CH_4, 15 percent nitrogen, and 10 percent miscellaneous gases [53]. Gas production is a long-time affair, inasmuch as it is produced as long as decomposition takes place, and decomposition continues for many years after a fill has been completed.

Extensive studies have been made on the discharge of CO_2 and CH_4 from a fill to the surrounding environment [51, 54]. In one report it was estimated that CH_4 was discharged into the soil surrounding the fill being studied at a rate of 1,440 lb/air/yr, and that nine times this amount diffused into the air. In another report it is stated that an equivalent of 25,700 lb CO_2/yr entered the soil from a fill, and that 48 times that amount diffused out to the atmosphere through the fill's one-foot silt cover. In a determination of the rate of downward travel of the gas, the conclusion was reached that it would take 2.4 yr for the CO_2 to reach ground water which was 190 ft beneath the fill.

This brings up the importance of the ground water level with respect to CO_2 travel. The researchers noted that the CO_2 concentration built up rapidly at the 50-ft level, whereas it probably would take 15 yr to reach a concentration of 5 percent at the 200-ft level. The carry-away CO_2 at a 5 percent concentration in contact with ground water in the fill would be on the order of 1,200 lb CO_2/acre refuse/yr.

Horizontal travel proceeded at 0.093 lb/sq ft/yr in one site and 0.259 lb/sq ft/yr in another site. Attempts to prevent the diffusion of gases into the surrounding soil by placing a polyethylene sheet between the fill boundary and the surrounding soil met with only partial success.

The reasons for the concern about gas production and travel are many. The destructive potential of CO_2 once it enters the ground water level has been stated in the section on leaching. Hydrogen and H_2S probably would not be of significance, since the amount produced generally is negligible. Methane is of importance primarily because of its combustibility, and only secondarily because it is a "suffocating" gas. The high concentration of methane renders explosive the gas emanating from a fill in the presence of "normal" air.

In view of the biodynamics of a landfill, i.e., long-term decomposition and associated gas production, considerable caution is to be recommended before completed landfill sites are opened for human dwelling. When any kind of construction is completed over a landfill site, the immediate problem with gaseous diffusion is that of CO_2 which lasts for a few months. This period is followed by one of methane diffusion which may persist for many years. An example of the need for this caution may be found in the report by First et al. [55]. They describe a survey made of a housing development constructed on filled land. In graveled spaces under the dwelling units, unsatisfactory conditions were found to exist with respect to air composition. In some cases, the atmosphere contained less than 10 percent O_2, as much as 6 percent CO_2, and 20 percent methane.

Although blowers and fans may serve as remedial steps to dissipate gases collected in basements and gas-proof floor slabs may be used in construction, greater engineering ingenuity and more study are needed before completed landfills can be used for anything other than as recreational grounds.

When refuse handling practices in sanitary landfill areas are marked by carelessness, vector breeding in unprecedented proportions becomes a distinct possibility, and the way is paved for the spread of fly and insect-borne diseases. This is particularly true during warm weather and in situations where refuse storage at the site of generation is unsatisfactory. Having gained entry to refuse stored in inadequately covered garbage containers, flies lay eggs in enormous numbers. The latter are carried to the storage pit where slip-ups in effective compaction or complete coverage with soil permits their full development and release. Some idea of the number of the transported eggs can be gained from a consideration of results obtained by Barnes and Black [56, 57]. They found that an average of 1,128 fly larvae per can per week migrated from refuse cans to pupate before the combined refuse was collected each week. As many as 23,208 larvae had been counted from one can during a single week. House flies that develop in landfills can penetrate and emerge through five feet of uncompacted cover or through nearly six inches of compacted cover.

Composting. The public health implications of composting as a waste treatment process wherein a great many potentially dangerous pathogens are rendered innocuous or are killed, hinges largely on one critical factor, namely, the temperature to which the treated material is raised. At present the consensus is that the likelihood of the survival of any pathogens or of fly larvae and eggs becomes remote when the duration of exposure to the critical temperature level is sustained over a period of days and weeks.

Much work concerned with the effect of temperature on pathogen survival has been carried on in Germany [58-61]. For example, Knoll [58] made observations on the survival of the *Salmonella* groups *typhi-murium*, *cairo*, *infantis*, and *paratyphi*. His procedure consisted in inserting cultures of the organisms in gelatin capsules, placing the capsules in 100 grams of raw material contained in nylon bags, and dispersing the bags with their contents throughout a pile of composting material. After 50 days exposure to the temperatures prevailing in the pile, all of the organisms had been killed. In another study involving *S. paratyphi B* and *S. typhi* [59,60], he found that the certain destruction of *Salmonella* strains cannot be assured in zones in which the temperature does not exceed 45°C; whereas complete decontamination can be attained within one day in zones in which the temperature is 65°C. Survival in terms of number and duration between these temperatures is a function of increase in temperature. Strauch [61], using *S. enteriditis*, *Erysipelothrix rhusiopathiae*, and the psittacosis virus, found that these organisms are completely destroyed under similar conditions. However, when he added *Bacillus antracis* to the collection, he found that the latter were only killed when the exposure period was three weeks or longer, temperature in excess of 55°C, and the moisture content 40 percent or higher. He also reports that the kill-off of anthrax is assured if the temperature of the composting material does *not* rise above 55°C during the first three days. The reason is that anthrax spores will germinate if the temperature is held at a point lower than 55°C. The organism is readily killed when in the ensuing vegetative stage. The organism has been observed to survive as long as 231 days in so-called "cold" composting processes, i.e., those in which the temperature does not exceed 55°C.

Elevated temperatures alone cannot entirely account for the reduction in pathogen number observed in composting refuse. An appreciable amount of kill undoubtedly is due to the mutually antagonistic effects found in cultures consisting of the wide variety of types of microorganisms found in composting material. The existence of this phenomenon was demonstrated by Knoll [59,60] in his experiments concerned with the effect of high temperatures. In a run, following the procedure described previously, he exposed one set of samples containing *S. paratyphi* B and *S. cairo* in a pile of composting material held at a constant temperature of 50°C, and simply incubated a second sample at the same temperature. In both instances, the moisture content was 50 percent. *S. paratyphi* were killed within two days and *S. cairo* within seven days in the sample placed in the compost pile; whereas *S. paratyphi* survived eight days, and *S. cairo*, 17 days in the incubator. He further demonstrated that the rapid kill-off in composting material probably is due to antibiotic effects in an experiment in which he placed samples of cultures of *S. paratyphi* and *S. cairo* in media containing an aqueous extract of composting material, and a second set of samples in media without the extract. The organisms were killed off within 10 days in the media containing the extract, and on the other hand, they survived for more than four weeks in the control medium. Knoll's conclusion is that the compost process, biological "self-purification," compensates for temperature inadequacies as far as pathogen kill is concerned.

Apparently resistant forms of parasites are destroyed during the composting process. Scott [62] found that the eggs of *Ascaris* and the cysts of *Endamoeba histolytica* and *Endamoeba coli* were completely destroyed within three weeks in windrow composting. In a more general statement, Scharff [63] reports that despite a heavy concentration of *Ascaris* eggs and hookworm eggs in night soil used in his experiments, he could find no trace of intestinal worm eggs after the material had been composting for three weeks.

Although the public health aspects of composting seem favorable with respect to pathogenic organisms, some doubt exists as to whether this also applies to pathogenic fungi. Characteristically, at some time during the composting process fungi became quite conspicuous because of their number. Judging from past observations [2], the greater part of the fungal population during this stage in a windrow operation is in the outer layer of the compost pile. The layer usually has a temperature within the range 45° to 55°C and generally is aerobic. In fact, in addition to that of temperature, the depth of the fungal layer seems to be a function of the degree of aeration as adjudged by the porosity of the material. The occurrence of a fungal stage usually is observed in mechanical compost processes, although because of the brief retention time in the digester proper, peak development of the fungal population is not reached until the composting material is windrowed for the "curing" or "maturing" step.

In their publication, McGauhey *et al*. [2] report isolating representatives of the genera *Streptomyces* and *Micromonospora* in the actinomycetes, and of two thermophilic fungi, *Aspergillus fumigatus* and *Penicillium dupontii*. Knoll [59] lists in addition to those found by McGauhey *et al*., members of the groups *Geotrichium*, *Mucorinae*, *Sporotrichium*, *Trichoderma*, *Gliobotrys*, *Torula*, and *Phialophora*. The list was lengthened by von Klopotek [64] to include *Cladosporium*, *Debaromyces kleockeri*, *Candida parapsilosis*, plus many others. This long list includes some genera which have species known or suspected as being pathogenic under certain circumstances to human subjects. The wide variety of the organisms indicates that fungi readily survive the composting process, although the extent of survival is a function of the group's thermotolerance. It also indicates the possibility that truly pathogenic forms may survive, and hence the need for intensive research in this direction. Work along this line is being conducted by the research group at Johnson City, Tennessee [65].

Another important public health aspect of composting that warrants attention is concerned with the dispersal of certain minerals and chemicals in the surrounding environment. Some of these may be released in such minute amounts as to constitute no hazard; however, no safe conclusion can be made until more is known concerning the composition (i.e., chemical) of the refuse subjected to composting. A published analysis of trace elements found in Dutch V.A.M. compost [66] indicates the following concentrations, expressed as percentage of the total dry weight of the refuse: Cu 0.01-0.06%, Mn 0.002-0.03%, Zn 0.007-0.023%,B 0.005-0.007%, Mo ± 0.001, and Mg (as MgO) 0.11-0.34%. Another important group of substances which may be found in compost or escape from the compost plant to the environment are the pesticides and herbicides. The concentration of such compounds in certain types of refuse may be great enough to constitute a definite hazard. Agricultural wastes undoubtedly would be the greatest offenders in this regard. The Berkeley laboratory of the National Canners' Association presently is conducting a study of the stability of pesticide residues in composting agricultural wastes.

OCCUPATIONAL AND GENERAL HEALTH HAZARDS

The possible health hazards suggested in Table 29 seem more numerous in the case of persons directly occupied in the business of collecting, transporting, and disposing of wastes than of the public in general. However, the health-related factors noted in the preceding section as being associated with burning, landfill, and composting have general implications since polluted air, contaminated water, and infected land are the avenues along which pollutants move from environment to man. On first analysis the hazards to the public which emanate from solid wastes disposal do not seem to be particularly serious; and it may well be that further study will support such a conclusion. Nevertheless, such further study is advisable because, for example, the stack discharges from refuse incinerators have been analyzed principally for the types of effluents known to derive from the burning of fuels of a more homogenous nature. It therefore remains for definitive research to reveal what hazards, if any, might be added by the presence of such materials as plastics, asbestos, cadmium, beryllium, pesticides, etc. not found in normal fuels but likely to appear in mixed refuse; and to determine whether such hazards have a macro-environmental effect.

Evidence of the occupational hazards associated with solid wastes management is both definitive and presumptive. Most definitive studies have been made on the health of persons involved in the collection of refuse, or on the incidence of industrial type accidents to workers involved in the disposal process.

One of the most extensive studies relating municipal refuse collection to occupational health hazards has been reported by Dr. Sliepcevich [67]. The study involved the effects of work conditions on the health of the uniformed sanitation men of New York City. The long-term health effects on one 500-man group, and the current health level of another group of 8,528 men, were investigated. The results led to a number of significant conclusions.

1. Arthritis may be classified as an occupational disease of refuse collectors.
2. Cardiovascular diseases may be classified as occupational diseases of refuse collectors inasmuch as the incidence of these diseases in the sanitation occupation exceeded all other groups of similar ages.
3. There is a positive relationship between the age of workers or years of service and arthritis and cardiovascular diseases.
4. The prevalence of muscle and tendon diseases among sanitation men is very high, particularly muscle ailments affecting the back. These diseases may be classified as occupational for refuse collectors.
5. Skin diseases may be classified as occupational for the refuse collectors. Some interesting points made by Dr. Sliepcevich include:
    a. The amount of daily lifting done by a sanitation man equals lifting a 24- or 35-lb can to the top of the Empire State Building.
    b. Lifting a 60-lb load requires 3-1/2 hp of energy (46 in lift of 60 lb).
    c. The work of sanitation men consists of a chain of sudden bursts, the intensity of which varies from medium hard to extremely hard. These strenuous exertions can be continued only because there are

periods of recuperation when the worker carries the empty can back to its resting place.

d. More consideration was given to the mechanical devices than to the workers. For example, facilities to maintain cleanliness were deplorable in the men's locker rooms; whereas the collection trucks were kept cleaner than the men were able to keep themselves. (This is changing — the more modern scavengers and city service departments are urging cleanliness of the crews — more for public relations.)

6. Hernia may be considered as an occupational disease for collectors.

7. Injuries to the hand are the most common injuries.

8. Older men tend to have less injuries than the younger men.

9. The injury frequency rate decreases as the years of service increase.

10. Sanitation workers have an extremely high injury frequency rate, exceeding that of all other occupations previously studied except logging. (N.B. — this in 1955.)

There is need for similar studies of the occupational hazards associated with disposal techniques such as landfilling and incineration. Recent indications, for example, are that aerosals may present a health hazard by transmitting disease vectors to men engaged in grinding refuse for composting or in mixing sewage sludge with refuse for composting.

VI. TECHNOLOGY OF SOLID WASTES MANAGEMENT

INTRODUCTION

Studies of the technology of solid wastes management have proceeded along three main lines of approach:

1. Improvement of existing technology — incineration, composting, landfill, and salvage.

2. Adaptation of existing processes to a wider spectrum of wastes — anaerobic digestion with sewage sludge.

3. Application of known processes to the development of new technology — wet oxidation, biological fractionation.

During the period herein reported, active research has been directed to six of the seven aspects of solid wastes management listed in the three foregoing categories. The seventh, landfill, is scheduled for experimental work later in the program. Both land surface and underwater fills are of concern. The rationale underlying the approach to each of the six aspects investigated is set forth at the appropriate place in each of the following sections.

INCINERATION

Burning is one of the oldest methods of dealing with the organic fraction of solid wastes. As suggested in an earlier section (Figure 1, type 4), it represents the only important current method involving "change of state" as the basic principle of operation. In its systematized application to municipal refuse it has advanced through the years from simple open piles or pits to highly mechanized engineered systems which at best are capable of reducing organic matter to a sterile ash having some 10 percent of the original waste volume. The remainder is discharged to the atmosphere as gases and particulates. In the most favorable geographical situations and from the best designed and operated plants this discharge represents a tolerable pollution of the atmosphere. At its worst the process is capable of creating objectionable air pollution producing nuisance from fly-ash, and leaving a residue of 15 to 25 percent of the original volume of solid wastes. For many large communities, however, where the value of land for landfill operations is an overriding economic factor, incineration (whether at its best or at its worst) is widely practiced and may be expected to be used in the future. This being the case, it is important to consider the nature of problems to which research and development should be directed.

One of the most urgent unsolved problems is in the area of economics: how to meet increasing standards of air quality, aesthetics, and related considerations at a cost the public is willing to pay. While the addition of precipitators and water sprays to remove particles, scrubbers to remove sulfur dioxide, chemical systems to remove other gases, etc. are all scientifically feasible, they involve great expense. Carried to the ultimate they are illogical in that their purpose is to change the incinerator effluents back to the solid state again, converting air pollutants once again to water and land pollutants, albeit in an altered form.

A second area of unsatisfactorily resolved problems is technology. A change in nature of solid wastes, particularly in the content of plastics, as well as an increase in the scope of community wastes which might be incinerated suggest that better mechanical systems are required.

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Some of the problems of economics and technology are capable of resolution only through plant-scale development and demonstration projects. Others are amenable to research techniques such as those hereinafter considered.

Concept and Rationale

Several concepts underlie the research herein reported. First is that incinerators are capable of better performance than has been the past experience in many cases. Public attitudes toward refuse, as noted in a previous chapter, have not been conducive to expenditures for wastes management. Too frequently performance has been sacrificed to minimize capital investment and operating cost. An already marginal, or even poor, situation is then further worsened by both an increase in the population generating refuse and in the per capita waste-generating rate. Consequently, incinerators operating at well in excess of 150 percent of design capacity are by no means rare.

Almost inherent in the operation of incinerators is the receipt of some 80 percent or more of the incoming refuse in approximately six hours. Therefore, if combustion is to be carried out continuously refuse storage is required to smooth out the flow to the furnace. Storage, however, particularly in the hotter months, can present the problems associated with putrefying organic matter. Ideally, then, it would be desirable to convert the as-received refuse into some form which would not give rise to such storage problems.

Accompanying the storage problem is that of heterogeneity of the incoming waste — a situation certain to worsen if a wider spectrum of community wastes are brought to the incinerator. Efficient burning, constant furnace temperature, and utilization of waste heat all depend upon a uniformity of fuel, as well as control of the rate of its injection into the furnace.

Looking at industrial furnaces or boilers, current technology seems to be quite capable of producing clean, efficient combustion of gaseous and liquid fuels. Sulfur oxides removal now seems feasible by several routes. Coal can be burned quite efficiently in powdered coal systems, and the fly-ash removal can be as complete as public authorities demand. If the refuse could be converted into a char or coke, either of which is quite friable, powdered coal technology could be used in refuse incineration.

The combustion of solids necessarily involves surfaces where the fuel and the air must be brought into contact. Also, the time for the complete combustion of a small object is less than that for one that is larger. Therefore, grate speed in a furnace could be increased, thus increasing the capacity, if a uniformly-sized feed were available. With a nonuniform feed, either the grate speed must be adjusted to achieve complete burnup of the largest objects or incomplete burning must be accepted. Thus, investigation of size reduction methods for the refuse might well be warranted.

Objectives

In accord with the foregoing rationale it is the specific objectives of the research team concerned with the technology of incineration to explore the scientific and technical feasibility of converting the organic fraction of solid wastes into a storable solid or gaseous fuel of relatively uniform heating value prior to charging it into a furnace, either with or without the production of marketable by-products.

During the period herein reported investigative work has proceeded along two lines:

1. Preliminary feasibility studies of refuse pretreatment.

2. Studies of pyrolysis as a specific method.

Refuse Pretreatment Studies

In this aspect of the work preliminary design studies were made of the equipment and plant necessary to produce a fuel of nearly uniform heating value and particle size from typical urban refuse and garbage. Assuming currently used collection systems and concepts of economics, the prospect of producing a relatively homogeneous fuel which might be utilized over a period of time by a power-generating furnace does not seem particularly bright. Among the several problems encountered were segregation, particle size reduction, and drying.

The least costly and most efficient method of segregation is, of course, at the source of waste generation. This poses no problem in the case of animal manures, agricultural residues, cannery wastes, and minor activities which involve essentially only organic residues. The construction industry, however, cannot conceivably separate its wastes under any foreseeable concept of economics. Dismantling of buildings board by board, while possibly desirable from a resource conservation viewpoint, is only feasible within the U. S. standard of living if combined with publicly financed welfare and other manpower support programs. This would require a whole new political concept that may or may not come to pass in the future. Segregation at the source of waste production by the construction industry itself is equally infeasible without public subsidy; and if such cost were to be assumed by the public, segregation after collection would be far less costly than segregation at the source.

In the case of household refuse, segregation by the producer of wastes is out of step with the whole trend of the U. S. culture of convenience and a national economy based on consumption (i.e., discarding) of goods. Furthermore, it is contrary to the wishes of citizens and few public officials are anxious to try to impose household segregation of refuse upon an unwilling electorate.

The possibility that salvage might be made to overcome the cost of segregating refuse was given consideration, while a full discussion of the salvage problem is reserved for a following chapter, it is evident that under present economic and social concepts it is uneconomic on any large scale. This results from high labor costs for sorting and low market prices for many salvable commodities. Obviously some degree of segregation is needed, and is currently practiced, in incineration. However, it must be concluded that the greater degree of segregation which seems necessary for the production of a homogenous fuel cannot be achieved without a change in current practice and current concepts of economics.

The point has been made in a previous section that the whole problem of solid wastes management calls for a reassessment of both economic and technological assumptions. Applying such a prospect to the field of incineration, the question of segregation of refuse becomes less dismal. Papers, particularly kraft, because of its volume appears to be amenable to a mechanized separation process. Thus salvage of paper might become a greater economic facet in segregation for incineration. Separation of noncombustibles from organics may not be necessary if particle size reduction is first accomplished. Some incinerator operators feel that cans and bottles help keep the fuel bed permeable to air. Thus hammer mills, followed by ballistic separators if necessary, become a feasible part of the refuse pretreatment plant producing homogenous fuels.

For demolition debris, float and sink methods have been suggested for separating wood from heavier components. No doubt, some rough initial size reduction would be required, possibly by hammer mills. For large objects such as utility poles specialized size reduction machinery is needed. Among the units considered are guillotine-type shears, chain saws, and extremely heavy duty sawmill hogs. The problem is, of course, complicated by the inevitable presence of tramp metals but the problem is certainly not insurmountable if refuse pretreatment should become an accepted concept of incineration practice.

Drying of wet refuse to make it less putrescible and more storable appears to be too costly to consider as a separate process. However, the conventional drying grates in an incinerator furnace at present are obviously performing this function. There is no reason why the dried refuse need go directly to the furnace from the drying grates, routing it to storage where part of its elevated temperature is used to preheat water for steam production as an incinerator by-product is a relatively simple problem in mechanical engineering design. As for steam and power production by the incinerator, the fact that it has been considered inconsequential in the past is not significant. Lack of homogeneity of fuel and limited freedom to supply fuel as needed has been the principal drawback. A shift of objective from that of simple refuse disposal to power production using fuel salvaged from refuse is the initial step. The second step involves an upgrading of economic concepts of refuse management to the level necessary to solve the problem.

Inasmuch as the first of the foregoing steps is feasible and the second inevitable, further investigative work on the nature of equipment and plants necessary to pretreat refuse and burn it productively, as well as on the economics of the system, seems clearly desirable. Experimental work along these lines is planned for later in the research program. The first work contemplated is an investigation of the effect of preliminary size reduction on incinerator capacity and performance. Ultimate plant-scale experiments are to be encouraged but are, of course, beyond the scope of the research program herein reported.

Pyrolysis Studies

In the production of a relatively uniform fuel from organic refuse, the ideal situation might be one in which preprocessing of organic matter returns important fractions to the industrial resources of the nation and the residue becomes a fuel for incinerator furnaces. Thus the method noted as "Indirect recycling" (Figure 1, type 6) would precede the "change of state" represented by incineration. Such a procedure would be doubly desirable because of its combination of resource conservation and economic wastes management. Pyrolysis represents one method of achieving this ideal situation and has hence been given attention by the research team interested primarily in incineration.

Pyrolysis or destructive distillation of most organic materials results in the formation of three classes of products: 1) a solid residue, or char, composed of elemental carbon and ash; 2) a condensable liquid product, water plus mixed organics; and 3) a gas of rather low heating value, but definitely combustible. Advantages of the process include the following:

1. The pyrolysis products should all (except for the water and ash) be combustible as fuels with existing technology and minimal air pollution.

2. The pyrolysis products, if used as fuel, should present less of a storage problem than refuse or garbage.

3. The possibility exists for the recovery of saleable by-products, as for example, acetic acid, methanol, and mixed solvents.

The first stage of the investigative work was to prepare a quantitative flow diagram, material balance, and energy balance. This work was based on information from the technical literature on the composition of urban refuse, on wood and coking coal destructive distillation, and on the fragmentary data available on the pyrolysis of specific materials [11,68-73]. The flow diagram for the visualized process is given in Figure 15. Tables 35, 36 and 37 present the data used on the as-received refuse, and the refuse after removal of some of the noncombustibles and drying. Table 38 summarizes the material balance, omitting any estimate of the organic fraction of the total liquids, which apparently can vary from 2 to nearly 8 percent.

A large laboratory or small-scale pilot plant to check the material and energy balance, and to obtain operating data as well as produce samples for separation process evaluation, is now being designed. This unit is to have an approximate throughput of 40 lb/hr of dried refuse.

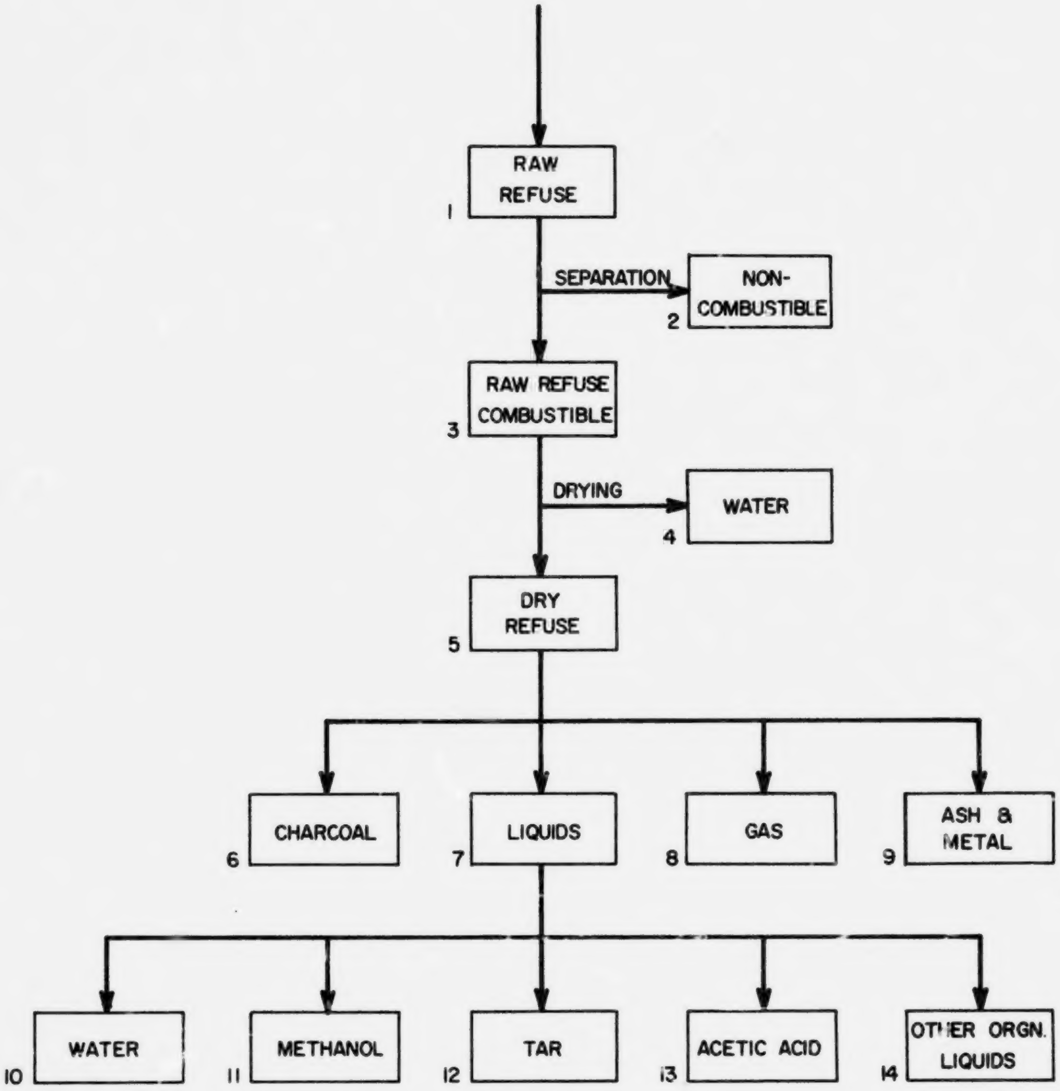
RAW REFUSE
1
SEPARATION
NON-COMBUSTIBLE
2
RAW REFUSE COMBUSTIBLE
3
DRYING
WATER
4
DRY REFUSE
5
CHARCOAL
6
LIQUIDS
7
GAS
8
ASH & METAL
9
WATER
10
METHANOL
11
TAR
12
ACETIC ACID
13
OTHER ORGN. LIQUIDS
14

FIGURE 15. MATERIAL FLOW OF REFUSE PYROLYSIS

TABLE 35

COMPOSITION AND ANALYSIS OF A COMPOSITE MUNICIPAL REFUSE (1966)[a]

1	Corrug. paper boxes	23.38%
2	Newspaper	9.40
3	Magazine paper	6.80
4	Brown paper	5.57
5	Mail	2.75
6	Paper food cartons	2.06
7	Tissue paper	1.98
8	Wax cartons	0.76
9	Plastic coated paper	0.76
10	Vegetable food wastes	2.29
11	Citrus rinds and seeds	1.53
12	Meat scraps, cooked	2.29
13	Fried fats	2.29
14	Wood	2.29
15	Ripe tree leaves	2.29
16	Flower garden plants	1.53
17	Lawn grass green	1.53
18	Evergreen	1.53
19	Plastics	0.76
20	Rags	0.76
21	Leather goods	0.38
22	Rubber composition	0.38
23	Paint and oils	0.76
24	Vacuum cleaner catch	0.76
25	Dirt	1.53
26	Metals	6.85
27	Glass, ceramics, ash	7.73
28	Adjusted moisture	9.05
		100.00

[a] According to Kaiser, cf. Reference [11].

TABLE 36

CHEMICAL ANALYSIS OF RAW REFUSE

Item	Percentage by Weight
Moisture	20.00
Carbon	29.83
Hydrogen	3.99
Oxygen	25.69
Nitrogen	0.37
Sulfur	0.12
Ash and Metal	20.00
Total	100.00

TABLE 37

CHEMICAL ANALYSIS AFTER DRYING AND SEPARATION (20% MOISTURE AND 9% ASH AND METAL ARE REMOVED)

Item	Percentage by Weight
Hydrogen	5.6
Carbon	42.0
Oxygen	36.2
Nitrogen	0.5
Sulfur	0.2
Ash and Metal	15.5
Total	100.0

TABLE 38

SUMMARY OF THE MATERIAL BALANCE CONCERNED WITH THE PYROLYSIS OF MUNICIPAL REFUSE

Item	Percentage		
	In	Out	Removed
Raw Refuse (analysis as in Table 35)	100	100	
Separation of Inorganics	100	91	9
Drying	91	71	20
Analysis after drying (see Table 37)			
Products from Pyrolysis			
Charcoal			11.25
Liquids			40.8
Gas			7.95
Ash and Metal			11
			100

COMPOSTING

Of the possible processes for converting organic solid wastes to products more readily utilized, composting has been given widest attention. Although most studies of the process have been directed to the production of a soil conditioner marketable in agriculture, the possibility of simply reducing the volume of material going into a landfill, or producing less "insult" to the land resource, has not been overlooked. Following studies by the University of California in the early 1950's [2] which established the parameters of aerobic composting, various attempts were made to apply the process to municipal refuse on a commercial basis. Progress has, however, been slow because orientation of agriculture to commercial chemical fertilizers, and other related factors, has made marketing of the product all but impossible on any appreciable scale. Of particular significance is the fact that investment in an uncertain process based on connecting a low-value raw material owned by the public to another low-value material for which there is little immediate demand is not economically attractive to private industry. At the same time the public is reluctant to make long-term commitments to pay private enterprise to accept its wastes and is in no legal or political position itself to develop and operate a commercial composting plant.

Recognizing the possibility that the time lag between the production of compost and agricultural demand for soil conditioner may encompass many years, the United States Public Health Service demonstrated that compost made from municipal refuse can be compacted in a landfill and so stored for use at some future time. This, however, did not answer the question of who is to do the composting and at what profit or loss to whom. Consequently no application of the method has developed. Other experiments in which disposal of the waste rather than sale of the compost have been conducted on individual fractions of the solid wastes of a community.

Control of flies and other nuisances from animal manures has been demonstrated on various occasions; typical were early pilot experiments at San Quentin prison [74] and the Davis campus of the University of California. Solid wastes from fruit and vegetable canneries have likewise been successfully composted by the National Canners Association and the University [75].

Concept and Rationale

Essentially all of the composting experiments and experience in the U. S. have involved some selected fraction of the organic wastes of a community and a high degree of refinement of product. That is, segregation, shredding, screening, and other processing was applied to such fractions as organic municipal refuse to produce a product suitable for soil conditioning whether or not it ended as an agricultural soil or in a landfill. In either case the absence of a financial return from the product does not justify more than the minimum investment in processing necessary to reduce the volume of refuse and get rid of its attractiveness to insects and rodents.

The underlying rationale of the research program herein reported is that it might be possible to apply rough composting to such of the organic wastes of a community as can economically be assembled — domestic refuse, animal manures, demolition debris, sewage sludge, agricultural residues — and so reduce the volume and otherwise improve the suitability of the mixture for land filling. Thus conversion by composting might become a step in the preparation of organic wastes for land filling in which the reduction in land area needs and earlier use of the filled area by reason of its greater initial stability would at least offset the cost of composting. If then at some later data a compelling need to add organics to the soil should develop, the fill could be mined, compost screened out, and fill volume again made available for refuse disposal.

The rationale also encompasses the alternate possibility that in a particular instance a demand for compost for immediate use could be developed. In this case it is conceived that animal manures in the mixture might furnish the nitrogen needed in composting paper and other carbonaceous materials and so make rough composting feasible where it has not been so in the past. The idea would be to compost prior to segregation with only a minimum of shredding. Ultimately the partially composted organic material might be screened out and left to mature in a pile. The remainder would be subjected to salvage operations prior to disposal by land filling.

Objectives

The objectives of the experimental work are suggested by the concept and rationale underlying the project. Specifically they include exploration of:

1. The feasibility of assembling organic fractions of the overall solid wastes of a community which might complement each other in the composting process.
2. The minimum parameters of a composting process suited to:
    a. Preparing refuse for landfill with a minimum volume and "insult" to the land.
    b. Producing compost from mixed organic wastes at a minimum cost.

During the period herein reported no experimental work was undertaken. Research activity was confined to two facets:

1. Compiling references on the subject of composting and incorporating it in the project's retrieval system.

2. Making an on-the-site study of solid wastes management in Germany, with particular reference to the utilization of organics in agriculture.

Only the first of these two activities was supported by project funds. The second was made by Dr. S. A. Hart, one of the project investigators under other support for sabbatical leave from the University of California.

West German Studies

Inasmuch as experimental work on composting was scheduled for the second year of project activity in order to make possible the background study abroad, the project has produced more in the realm of ideas and concepts than concrete data directly applicable to U. S. conditions. Of particular interest is the contrast in attitude of farmers in West Germany and the United States in relation to the use of compost and other organic refuse on agricultural soil. West Germany has today 56 million people living on 94,500 square miles. With about 25 percent of the U. S. population and 3.2 percent of the land area of the U. S., West Germany produces 78 percent of its food supply. The average size of farm is but 24 acres, hence productivity must be high. One factor in this productivity is intense use of barnyard manure, compost, and other organics, and German agricultural science has found [76] that maintaining a high and constantly replenished soil organic content is one of the keys to continued high productivity. Thus the incentive exists for the farmer to route his agricultural residues back to the land and hence to prevent their becoming a part of the overall wastes management problems of the community.

The situation in the United States today is, of course, vastly different. We have plenty of prime agricultural land and are easily able to produce an abundance of food. Organic content of the soil does not have to be husbanded, although it seems desirable to do so in the western U. S. Thus the economic pressure for compost production from solid wastes does not arise in the U. S. from agriculture. In fact, the economics of U. S. agriculture tends to increase the volume of solid wastes which agriculture does not want in any form.

Nevertheless a significant lesson may be drawn from the German experience — i.e., it is possible to use the land and its ability to assimilate organic matter as a way of disposing of some of our solid wastes. While this is a relatively new approach to refuse management it does imply that if compost can be produced at an acceptable cost, agricultural land might be used instead of a landfill for its disposal. In this case the economics of refuse disposal rather than the economics of agricultural fertilization would become the controlling factor. Possibly the farmer might be paid for accepting compost rather than asked to purchase it.

Concerning the technology of composting several things can be learned from the West German experience. Eight plants erected since World War II continue in operation [76] to the present. None have been shut down. The general characteristics of each are indicated in Table 39. It is notable that all are in or near the wine-growing areas of Germany. Further, seven of the eight include sewage sludge in their input.

Extensive research on the survival of pathogens in the composting process has been conducted. The results show that there is a minimum time-temperature condition required for pathogen kill. In windrow composting this was observed to be 18 to 21 days at temperatures consistently above 55°C. At lower temperatures some pathogens lived 251 days. In the Dano drum 5 days were required — or 3 days, plus 4 additional days in windrow storage. At Heidelberg, where the refuse is ground before putting it in the Multi-Bakter Turns, pathogens were killed within 24 hours. These results seem to be directly usable under U. S. conditions.

From observations in West Germany, Dr. Hart draws several conclusions which have pertinence to project work planned for the future at the University of California:

TABLE 39

GERMAN COMPOSTING PLANTS

City and Plant Owner	Pop. Served	Operation Begun	Sludge Accepted?	Process	Net Cost to City per metric ton of raw waste accepted Compost Selling Price	Description of Operation
Baden-Baden City	56,000	1953	yes	Windrow composting of unground refuse	13.10 DM 10-12 DM/met ton	Magnetic iron removal plus hand separation, refuse mixed with sludge, and piled for 3-5 months without turning. An air-duct system for aerating the piles has not been effective. Finished compost is ground and sieved. Noncompostable residues burned if possible, and buried.
Bad Kreuznach Private, Farmers Organization	45,000	1958	yes	Dano drum without pre-grinding	10 DM 10 DM/met ton to Assoc. members	Magnetic iron removal, then unground refuse and sludge put in Dano drum for 3-4 days. Partially rotted compost is sieved, and piled in windrows without further turning. Oct-Dec disposal on grape land. Noncomposted sieve residue is buried on the site, thus raising the elevation of the storage area. Successful operation, mostly due to the demand for the compost.
Blaubeurin Private, Cement Manufacturer	20,000	1954	yes	Windrow composting of ground refuse	Estimate at 2 DM, seems low Set at 14.50 DM/ cubic meter for quarry reclamation	Plant was erected to produce compost to reclaim sand and gravel quarries. Hand separation of refuse possible but not always done, Dorr-Oliver rasp, then ground in hammer-mill, sludge added and windrowed. Three turnings. Finished compost used "as-is," mostly for quarry reclamation. Small incinerator for bulky noncompostables.
Duisberg-Huckingen City	120,000	1956	yes	Dano drum without pre-grinding	5.20 DM, presently good salvage income 9-20 DM/met ton	Refuse from only part of Duisberg is processed. Magnetic and hand separation, then unground refuse and sewage sludge into Dano drum for 3-day detention. Discharge sieved. Sieve residues to landfill. City is planning an incinerator. Compost plant does not run continuously due to odors from Dano drum.
Heidelberg City	30,000	1955, 1962, see disc.	yes	Multi-Bakter Turm, with pre-ground refuse	Estimated at 5-7 DM 13 DM/cu meter to wholesaler who distributes	Refuse and sewage from 30,000 (personal estimate, city estimates 60,000) of area's 160,000 residents composted. Magnetic and hand separation, Dorr-Oliver rasp, sewage sludge added, and mix goes to Multi-Bakter Turm. 3-day detention (mechanism runs only 8 hours per day). Discharge sieved and ballistically separated, ready for immediate sale. Residues are landfilled.
Schweinfurt City	85,000	1963	yes	Caspari-Brikkolare, with pre-ground refuse	9.10 DM 17-20 DM/met ton	85,000 of the 120,000 residents of the area served. Magnetic separation, Dorr-Oliver rasp, ballistic separation, then the ground refuse plus sewage sludge is pressed into briquettes. Stored three weeks on pallets in a warehouse where composting occurs. Removed and stored outside until ground and sold. Incinerator then landfilling for residues not composted.
St. Georgen (near Freiburg) City	14,000	1963	yes	Windrow composting of pre-ground refuse	33.50 DM, high due to small size and complete disposal by composting 13.50 DM/met ton	Smallest plant, but accepts total solid wastes from 2 communities and makes everything into compost. Magnetic and hand salvage, noncompostables burned and the ash returned to refuse which is ground and mixed with sewage sludge. Piled for 5 months, with 3 turnings. Not in continuous operation although equipment is large enough.
Stuttgart-Mohrigen City	75,000	1959	not now	Windrow composting of pre-ground refuse	7.20 DM 5 DM/met ton, with only a portion sold	Only a part of the Stuttgart solid waste is made into compost, rest goes to landfill (with some incineration first). Magnetic and hand separation, then rasp-sieved and ballistically separated. Placed in windrows, 2 turnings in 3 months' time.

1. Sewage sludge disposal is an important factor in the reasoning behind composting. Sewage sludge disposal has generally been a difficult part of the water treatment process of Germany, and part of the burden for the management of the sludge seems to have been turned over to workers in the solid waste field. Composting is an efficient and effective method of sludge disposal.

2. Health and sanitation problems should not be a serious obstacle to compost use. Careful scientific studies on pathogen inactivation have been conducted in Germany, and both the results and the techniques of study are appropriate to the U. S. Safe compost can be produced.

3. The various composting processes produce equivalent quality compost at apparently equivalent cost. The quality of the compost and the cost of producing it is more a function of the amount of "cleaning up" of the material than of the nature of the raw material or the method of composting. The grinding, sieving, and separation can be done either before or after composting, but the higher quality compost is produced with some final sieving and separation. It also appears that there will be no great new economies due to new processes, although mechanical processes do save space over windrow composting. A high quality compost contains less inert or objectionable material (glass shards, plastic, and ash) than poor quality compost, and can more economically be transported greater distances. The economics of quality improvement and transport logistics has not been worked out but certainly should be done.

4. Compost has its greatest market on luxury crops. The discussion and the data in Table 39 indicate that most of the compost is produced in the wine-growing region of Germany and is used on the vineyards. It is significant that compost presently seems to have value only on the luxury crops, and not basic agricultural soils and crops. There are exceptions of course, such as Blaubeurin, where reclamation of quarryland is the prime use. But finding an appropriate and expanded market for compost will be a most significant factor for future success of any composting plant.

5. Research is needed on compost utilization. Most people — laymen and professionals together — wish that the composting situation were more favorable. It is not, but this does not mean that composting or composting research should be abandoned. In addition to using compost for luxury crops and land reclamation, composting is appropriate for sludge acceptance, for reduction of the volume of waste going into a landfill, and perhaps other reasons. (Organic material as a container for poisonous material such as pesticides is a possibility and should be investigated.)

LANDFILL

As noted in a preceding section, no experiments on the technology of landfills was conducted during the period herein reported.

Extensive studies [3] of landfill previously made by the investigators, together with well established practice carefully analyzed on a continuing basis by numerous cities and by such organizations as the Los Angeles County Sanitation Districts, have effectively removed the technology of landfill from the list of areas in which research is likely to make spectacular contributions to solutions to the problem of solid wastes management. One exception to this generalization is undersea landfilling and it is this facet of the subject to which technological studies may be directed in the future.

Lack of research on the technology of landfills does not mean, however, that the sanitary landfill was ignored during the report period. As noted in a previous section, the land is considered the most important, and in many areas the only, sink capable of accepting all fractions of solid wastes; and landfilling is the technique of such acceptance. Considerable study was directed to the nature and fate of various fractions of refuse going into sanitary landfills in the context of their public health significance.

A great deal of attention was directed to the economics of landfills and to the interrelationship between landfill and land use planning within a community. Results of this aspect of the landfill studies are incorporated in this report in the sections on Public Health and Planning where continuing attention is being directed to the method.

SALVAGE

Diversion of fractions of the overall waste material from the wastes stream to the basic and natural resources of the nation is one example of the method called "Direct Recycling" (Figure 1, type 5). More commonly it is known by the name of "Salvage." The term, however, has been used rather loosely in practice to include both residues, such as metal scrap which was recycled within an industry itself and hence never a part of the "wastes stream," and materials and objects which are segregated from mixed refuse and returned to the resource. In this latter category are such items as rags, bottles, paper, nonferrous metals, metal cans, etc. which are destined for the landfill unless sorted out and reclaimed. A distinction must therefore be made between "reduction at source" and "direct recycling," (Figure 1 type 1 and type 5), because of both technological and economic considerations, when approaching the subject of salvage from a research viewpoint.

In the broader sense, including both reclaiming and recycling, salvage forms the basis of an enterprise estimated to range from 5 to 7 billion dollars annually in the United States. It is, in fact, an essential part of the economy in that were it not for the reuse of scrap materials there would be insufficient raw materials to meet the need of our basic industries.

Concept and Rationale

Several fundamental concepts underlie the study herein reported. To begin with, it is recognized that in spite of the magnitude and importance of the "salvage" business in the U. S., the so-called solid wastes management problem has assumed critical proportions. Consequently, of present activities under the title of salvage, it can only be said that without them the problem would be worse. What must now be considered is the way in which the present wastes stream can be reduced by direct recycling to the basic resources. Further, the concept of salvage or reclamation from this stream must be resources or conservation oriented, rather than simply cost or profit oriented. Again the social objectives of man must be combined with his desire to be rid of unwanted residues and an appropriate concept of economics must be applied.

Within the rationale of conservation it seems logical to assume that wastes are simply the residue of resource use, and as such they represent "resources for which we have not yet found a use." While so extreme a view may not be practical it does lead to the concept that the ideal solution to the solid wastes management problem is one which results in the maximum reduction in the generation of wastes by way of reuse or recycling, and the disposition of the irreducible residue in a manner devised to enhance or conserve the value of the final disposal site.

Another concept underlying the study is that direct recycling is most readily carried out in situations in which the waste is relatively homogeneous and high in value. These conditions prevail most frequently in commercial and industrial operations. On the other hand, when salvable material is mixed with garbage and other refuse, its reclamation is difficult because the main control of salvage and reclamation is economics. As a result, salvage in municipal operations is relatively limited and sporadic in occurrence in place and time. This difficult fraction cannot be ignored, however, because it does represent a sizable portion of our wastes (or resources).

An advantage to be gained in making salvage an integral part of a waste management system would be the establishment of a dependable and continuous supply of raw materials, the lack of which is a problem for some industrial salvage operations. However, this continuity of supply would make it necessary to keep processing and salvaging operations active and base economics on something other than current marketing conditions.

Another important consideration with respect to the supply of those components which cannot be utilized in full is the need to develop new markets for them or, more appropriately, reprocess them via an indirect recycling procedure (Figure 1, type 6) to produce a raw material for some other industry.

Objectives

Pursuant to the general rationale set forth above, study was directed to a determination of those qualities or conditions in the socio-economic environment which limit or prevent the orderly return of fractions of the waste to the basic resources of the nation. Subsequently, the objective is to develop a framework for a broad recycling scheme which can be enlarged or modified to fit in with technological developments or changes in local circumstances.

The Investigation

Investigative work herein reported involved a search for imformation from three major sources:

1. The literature;
2. Scientists whose background gives them an expertise with respect to certain components of the wastes;
3. Processors and salvors who deal directly with the components.

Information obtained from the processors by way of interviews reflect the practical realities of salvage. The operators interviewed are presently engaged in recycling those commodities which by reason of cost (including negative cost) can make the enterprise economically justifiable. Through the interviews, the nature of many of the conditions which mitigate against reuse were ascertained. These conditions constitute the specific problems which must be solved by research or pilot-plant studies under present economic assumptions. They may be materially altered if the operation is conducted as a public enterprise, simply because some social benefits which accompany the operation may be great enough to compensate for any economic deficit.

Specific studies were made of such fractions of solid wastes as metals, paper, glass, rubber, plastics, and rags, with the following principal findings.

Metals. Because of their high value and ready market, the salvage of scrap metals other than tin cans and abandoned automobiles is fairly complete, not only with respect to industrial wastes but also to domestic wastes. Consequently the problem of the disposition of scrap metals resolves itself to one of handling the tin cans and the abandoned automobiles.

"Tin" Cans: Tin cans are salvaged in California and in other states for use in the recovery of copper from tailings and low-grade ores in copper smelting operations in Montana, Arizona, and Nevada. According to C. C. Sexton [78], a private salvor who was interviewed on the subject, the salvage of cans from dumps takes place in three steps: sorting, burning, and shredding. The cans are burned to de-tin them, and are shredded to compact them for shipment. Cans salvaged from incinerators naturally require no further burning. They are removed from the ashes by a magnetic sorter, are screened, and finally shredded for shipment.

At the copper mines, the cans, along with light-gauge sheet metal and scrap from de-tinning operations, are used in the extraction of copper. In the process an acid solution is percolated through tailings or low-grade ore to dissolve and remove the copper. The acid-copper solution is collected and is then pumped into large tanks filled with shredded light-gauge iron. The iron replaces the copper in the solution, and the copper is precipitated in the form of pure copper nodules. It is readily collected in this form. According to Mr. Sexton, the demand for shredded light-gauge iron by the copper industry is steadily increasing and is in competition with that of other users. Thus to help meet its needs, a major copper mining company developed a process for making a low-grade sponge iron from slag. However, its application is not proving very successful because of the high production cost and the need for a certain amount of light-gauge iron in addition to the "sponge" iron. Apparently not all of the copper is removed by the sponge iron, consequently it is necessary to use the light-gauge iron to precipitate that copper remaining in solution.

Uncertainty exists as to whether or not the copper extraction industry could serve as a market for the entire output of can salvage if the salvage operation were extended throughout the United States. Consequently, other uses should be sought for salvaged cans. One such use might be in the tertiary treatment of sewage. The cans would be converted to ferric or ferrous chloride by processing in a chlorine solution. The chlorides would then be used as coagulants in precipitating colloids from the treated sewage. This method was tried in the 1930's in the secondary treatment of sewage. (It was later superseded by biological methods.)

Abandoned Automobiles: Salvage of abandoned automobiles was the subject of an interview with Mr. M. Seiden [79], a private metal salvor whose operational base is in Los Angeles. Mr. Seiden is of the opinion that the problem of the abandoned automobile is one of economics and that it is more of a problem in suburban and rural areas. When an automobile is abandoned in a city, it usually is impounded by the police department and hauled away to storage. After due process of the law (held for 30 days in California) it is auctioned off to junk dealers. Generally, the cash return is insufficient for defraying the handling and storage costs. In effect, therefore, the city subsidizes a part of the cost of disposing of the abandoned automobile and recycling it back into the manufacturing cycle

Various schemes for financing the collection costs have been tried. For example, the state of Pennsylvania appropriated 4-5 million dollars for use in removing abandoned autos. The project was abandoned after it was found that more than 2,000,000 abandoned cars would have to be handled — a number which would permit the expenditure of only $2.00 per car. The actual cost per car was from $15 to $20. Sweden is more progressive in its approach. A part of the purchase price of new cars is retained by the government for future use in paying for the disposal of the car at the end of its useful life.

Once the liabilities in junking an abondoned car are cleared and the car is sold to a junk dealer, the next problem is to transport it to a fragmentizer. The cost of transporting an abandoned automobile in Bozeman, Montana, for example, to the nearest fragmentizer may be as much as three times its scrap value. As far as the processor is concerned, he must be adjacent to steel making or ship loading facilities to make his operation financially successful.

The abondoned automobile ceases to be a solid wastes problem once it is in the hands of the processor. The development of the modern fragmentizer has made it possible to process the junked car into high-grade scrap suitable for steel making. However, chrome plated parts and copper wire represent a nuisance in auto reclamation, as does the burning of upholstery, etc. in areas where air pollution is a factor.

Status of the Scrap Metal Industry: The market for scrap has been on the decline in recent years because of the use of less scrap per ton of steel produced. The reduction in need is the result of modern technological developments. Another reason for the decline in demand is the competitive challenge of the cost of scrap as a raw material.

One of the troublesome problems in salvaging automobiles is the quantity of wastes that is generated in processing it. From 20 percent to 25 percent of the total weight of the junked automobile is in the form of unusable material such as glass, rubber, plastic, and dirt. This material must be disposed of, a need which in itself creates a waste disposal problem for the industry. An example of the magnitude the problem can attain in a large-scale operation is that of the Proler-Nhu plant in Los Angeles which produces some 200 tons per day of unusable material that must be disposed of off the site. At present it is disposed of by landfill.

To meet the challenge occasioned by technology, by rising costs, and the requirements for higher quality scrap, the Luria Company has developed new methods for processing what would normally be low-grade scrap into high-quality material. This is done by passing the material (used automobiles, refrigerators, stoves, etc.) through a fragmentizer, which removes the 17 percent to 20 percent nonferrous component of the material. The processing is completed by an electromagnetic separation of the ferrous material. Nonferrous metals are recovered by a flotation process (as yet in the developmental stage).

A factor that has stimulated the scrap business in recent years is the increased foreign demand for U. S. scrap. For example, Japan is a major customer for scrap. It obtains 95 percent of its needs from the United States. The market also has been stimulated by the war in Viet Nam.

Nonferrous Metals: According to Mr. Learner (president of the Learner Company) nonferrous scrap can be profitably segregated by hand and bundled for shipment to secondary users or refiners [80]. Hand segregation is economically feasible because of the high market value of nonferrous metals. Examples of current prices are as follows: aluminum scrap, $0.10 to $0.12/lb; copper scrap, $0.30 to $0.40/lb; brass scrap, $0.25 to $0.40/lb. (Iron scrap sells for about $0.01/lb.)

In summary, it may be stated that the scrap metal industry in the United States is a healthy one. Using the dollar volume as an index, it is one of the ten leading industries in the United States. The industry is interested in research on ways to upgrade scrap in order to widen its application in steel and other manufacturing industries.

Paper. Paper probably is the component of domestic and commercial refuse that may have the greatest salvage potential. Certainly it is the largest individual component in terms of weight and volume, constituting 45 percent of the municipal solid waste generated each year. If segregated and satisfactorily processed for reuse, it would have the greatest potential market value. Indeed, in 1966, an estimated 10 million tons of paperstock were recycled and became raw material for a wide range of new products. The benefits accruing to a community as a result of salvaging this sizable portion of the total refuse has been well summarized by Russell [81]:

1. Reduction of the waste disposal problem;

2. The employment opportunities provided by the collection system;

3. Provision of approximately 25 percent of the raw material for one of the nation's greatest industries – paper and paperboard;

4. Conservation, in that trees are not cut because of availability of fiber from wastepaper;

5. Fund-raising opportunities for charitable groups.

Classification: In industrial salvage, paper is segregated into grades established according to a method of classification based on waste paper standards adopted by the Waste Paper Institute, a division of the U. S. National Association of Waste Materials Dealers [82]. Although the classification is reviewed and revised from time to time, the general basis on which the gradation is made remains unchanged. This basis is the extent to which a given waste paper is a source of paper fiber which can be used in the production of a paper with a high Mullen index (strength), is amenable to refining, and possesses a high brightness index. In general, the top grades of salvaged waste paper are those which consist wholly of unprinted white paper manufactured from bleached chemical pulps free of contamination by foreign material. Comprising the lowest grades are the unsorted mixtures of papers of a variety of qualities, as well as those which may contain material not of use in paper making. Strong, clean papers (even though colored) command a high price because of their strength-giving qualities. Examples of this type are tinted sulfite papers and unbleached sulfate papers.

In one classification, the salvaged paper is divided into three groups according to volume of the source and use to which the paper may be applied:

1. Mixed waste paper and coarse paper material;
2. Paper whose fiber composition is mostly of bleached chemical pulps;
3. Clean, fresh wastepaper.

Group 1--Paper belonging to Group 1 is sorted into a number of grades as determined by composition and degree of cleanliness. In this class are old fiber containers and boxboard, old wrapping paper, paper bags, newspapers, and other coarse paper. Paper of this class is used in making paperboards on multicylinder machines. In the manufacture of high-grade paperboard, better grades of paper are used, such as newspapers, old kraft paper, unprinted waste book paper, and fresh chemical pulps.

Group 2--Examples of paper in this grouping are printed books, magazines, and other waste papers. These papers are de-inked by a combination of mechanical and chemical treatment. Once de-inked, the processed paper fiber is suitable for use as a supplement in the production of new pulp for use in the manufacture of book, magazine, and other high-grade paper.

Group 3--The clean, fresh waste paper which makes up Group 3 can be directly used in paper mills for the manufacture of similar papers or serve as a supplement to new pulp. This type of waste paper can be used without pretreatment other than that required to reduce it to a sludge or slurry. The reduction is accomplished with the use of specially designed machines. Examples of sources and applications for this type of paper are: clean waste ledger paper for the manufacture of writing paper; paper waste from binderies and magazine publishers for the manufacture of book paper; and clean wrappings and bag paper for the manufacture of coarse paper.

Problem Waste Paper: Wet strength and plastic coated papers are difficult to reclaim. In fact the recovery of wet strength paper probably would be a questionable venture inasmuch as a large part of it cannot be properly pulped and is lost with the trash that is removed from the pulper for disposal [83]. On the other hand, apparently economically feasible methods have been developed for recovering plastic coated paper. The paper in plastic coated cartons is being successfully salvaged in a local (Antioch, California) paper plant which processes the material along with other waste papers and some virgin pulp for use in the manufacture of printed boxboard and cardboard. Some appreciation of the amount of plastic (polyethylene) involved may be gained from the fact that about 15 lb of the material is used to coat 3,000 sq ft of paper surface. In the salvage operation, chemicals (usually wetting agents) are added in the pulping stage to loosen the plastic coating. Approximately 87 percent of the paper fibers are recovered in the operation. The polyethylene film becomes a problem only when it chances to become shredded into small pieces. The problem arises from the difficulty involved in removing the pieces from the slurry.

Contamination: According to local processors, the presence of contaminants in waste paper constitutes their biggest problem. The gamut of contaminants includes waxes, tars, latex, plastics, plastic foams, metals, and resins. Contamination with wax, tar, latex, or any other coating material can bring about the ruin of an entire batch, since this material forms a coating on the paper which interfers with the adherence of glue to the corrugating medium. Tramp metals can damage the papermaking machines, and plastics can plug up screens. Plastic foams are broken into small pieces in the pulper. These pieces can plug up screens or become embedded in the paper and are difficult to remove. Even though contaminated material may be used in some applications without fear of damage, the fact remains that contamination does severely limit the use of potentially salvable sources of paper fiber to lower applications in which the presence of contaminants is less critical. An example would be the use of a contaminated high-grade waste paper in the manufacture of roofing felt instead of in the production of high-grade paper for which it would otherwise be suited. Of course, an added economic penalty resulting from the presence of contaminants is the expense involved in removing and disposing of them.

Collection and Marketing: The chief sources of waste paper are office buildings, large retail outlets, transportation terminals, and apartment buildings in the larger cities. In the smaller cities it is collected by various local agencies. The small junk dealer and street pickers make some small contribution to the collection process, but only under certain economic conditions peculiar to the area in which the collecting is done. The collected waste paper next is passed through the hands of dealers, who have facilities for grading it into well-defined classes. The classified paper is then compacted, according to grade of paper, into bales ranging from 500 to 1500 lb in weight.

As is to be expected, the activities of organizations responsible for the flow of domestic paper to the waste paper packers are directly influenced by the market for the paper. A heavy demand for waste paper begets a high degree of activity among the dealers in waste paper. The degree of acceptability of the various grades of paper also is a function of the market. When the demand is brisk and the supply is ample, grades of paper acceptable to the waste paper consuming mills tend to be on the high side. The reverse is true when the demand continues brisk and the supply is short. An indication of the monetary value of waste paper used in boxboard manufacture when the demand is heavy and the supply is normal is given by prices listed in Table 40.

TABLE 40

PRICES PAID FOB STOCKTON
FOR PAPERMAKING STOCK[a,b]

Item	Price/ton ($)
No. 2 Corrugated Bulk or Filler	29
No. 1 Corrugated Bulk or Filler	41
Box Mill Cuttings	17
Polyethylene Coated	40
Unbleached Kraft Side Rolls	85
Bleached Kraft Side Rolls	111
Bleached Kraft Pulp	130
Bleached Sulfite Pulp	142
Baled Newsprint	28

[a] April 1967.

[b] Private communication 7 April 1967 from Mr. B. Streaker, Technical Superintendent, Fiberboard Plant, Stockton, California.

Glass. The addition of a certain amount of salvaged glass (cullet) to basic raw materials has long been practiced in the glass-making industry. The reasons for the practice are economic and technical in nature. With respect to the former, the use of cullet extends the supply of basic material, and to the latter, it favorably affects the processing and the quality of glass. One effect is an increase in the melting rate of the glass mix; which in turn makes possible an increase in production rate, a reduction in size and complexity of furnace, and in certain types of glass making, the production of a better quality glass than could be done without cullet. Another effect is the promotion of homogeneity in the molten glass, and thereby, an imporovement in quality of the finished product. The amount of cullet used in a given operation depends upon the type of glass to be produced. The amount may be as low as 10 percent of the basic raw material to as high as 60 percent.

The only exception to the general use of cullet is in the manufacture of certain glass products which have very critical specifications with respect to strength, light transmission, or other specific characteristics.

Sources: More than half of the cullet that is recovered and utilized in glass making comes from scrap dealers who collect and sort the material as a part of their scavenging activities; and from bottlers and others who either use or pack glass containers. Examples of members of the latter group are breweries, dairies, food packers, and drug and cosmetic producers. Except for the cullet generated and reused as "home scrap" by the manufacturer himself, the remainder of the cullet comes from manufacturers, such as sash, door, and window manufacturers; mirror makers; and others who use glass in the production of their products.

Composition: From 60 percent to 80 percent of the glass found in domestic wastes is in the form of bottles of various types, ranging from small pill bottles to gallon-sized wine containers. From 10 percent to 30 percent is composed of broken window panes. Glass from these sources is made up of "lime glass." A sizable fraction of the remaining glass is made up of discarded "TV" tubes, fluorescent lamps, and cut glass. Glass used in the manufacture of these items is "flint glass."

In the raw state, cullet is stockpiled chiefly according to color grade, viz., flint, amber, emerald green, light green, and opal. The flint cullet is separated into three classes — lime, lead, and borax. Flint glass of the lead variety comes mainly from "TV" tubes and similar products, from cut glass, high luster tableware, etc. Lime cullet comes mostly from food, beverage, and drug containers; while borax cullet is obtained from heat resistant wares such as pyrex.

Processing: In some cases, processing begins at the dealer's plant as a part of the sorting operation. When cullet arrives at his plant, it is fed on an endless belt for sorting. Here glass is removed and stored according to color and nature of the glass, and foreign materials such as paper, rags, and metals are removed. As the cullet leaves the belt, it is discharged into a crusher in which it is reduced to one-half inch to one-inch pieces. The crushed cullet is then moved to another sorting belt where foreign matter left from the preceding step is removed. Paper labels and other nonferrous contaminants are removed by hand; while the ferrous materials are separated by means of a magnet. In the next step, the cullet is washed to remove all remaining foreign matter. Suitable chemicals are added to the wash water. After being de-watered, the cullet is passed over a final conveyor belt for a last checking before it is stored or is packed for shipping.

Further processing is required for cullet which is to be used for the match and abrasive industry. The additional steps are passing the crushed cullet through rotary dryer and recrushing the material to the consistency of a fine powder by passing it through a roll mill. The powder is classified by means of an air-flow cyclone separator to a particle size equivalent to 200-mesh. The glass flour is bagged — usually in 100 lb portions.

An important function of the processing step is the removal of contaminants. For example, the presence of tramp metal in the cullet can result in damage to the furnaces in the form of erosion of the brick lining. In fact, the limestone supplier must use iron blasting caps in his quarrying operation in order to eliminate the possibility of any copper finding its way into the quarried limestone. Copper is an especially troublesome contaminant because it melts and settles to the bottom of the furnace thereby ruining the refractory brick liner. In addition to the danger of damaging the furnace, other requirements dictate the careful removal of contaminants. An important requirement is that of maintaining desired color characteristics or pigmentation, especially in applications in which color is the critical item. For instance, iron and copper impart a certain tint to the glass. Therefore, if a colorless glass is desired, care would have to be taken to remove these substances, even though present in only small amounts. Colored cullet would have the same effect as would metals, and hence would have to be removed when colorless glass is desired. Some glass itself may be regarded as a contaminant in the manufacture of special types of glass. For instance, admixtures of flint glass would be undesirable, and hence equal to contamination, in the manufacture of lime glass.

Special Applications — Containers: Very little cullet is produced in the manufacture of containers both because the selection rate is high and because no cullet is produced as a part of each article. Because of this fact and because of the characteristics imparted by cullet to the mix, it is necessary to bring in cullet from outside sources.

One source is in the salvage of glass found in domestic refuse. However, certain difficulties must be met before this class can be used. A problem arises from the fact that color considerations are important in the manufacture of containers. Another problem is the heterogeneity of the supply of glass obtained from domestic refuse since the composition of bottle glass varies from factory to factory. If flat glass is used, its composition also varies. The presence of laboratory and technical glass further complicate the situation. Nevertheless, if the entire mass of salvaged glass could be made into a homogeneous mixture by suitable pulverizing and mixing, and contaminants could be removed, the material could be compounded for reuse in the manufacture of amber or green glass containers.

Special Applications — Fiber glass: The fiber glass industry has often been mentioned as a potential large consumer of scrap glass, probably because to the uninitiated the manufacture of fiber glass would seem to be an operation with a minimum of critical requirements. To explore this potential, an interview was arranged with a local fiber glass manufacturer.* It was learned that the supply of basic raw materials presently is augmented by "home" scrap cullet. The mixing operation is engineered to produce a homogeneous molten mass of glass having a known, uniform viscosity. These characteristics are essential, since the viscous liquid glass must be passed through very minute orifices (diameters of 0.00025 to 0.0005 in.). The extruded glass rods are then transferred to a high energy field, in which are produced the minute glass fibers that make up the product fiber glass. Any foreign material not liquified in the furnace will plug the orifices. Moreover, at temperatures higher than 2000°F, tramp iron forms an amalgam with the platinum in which the orifices are drilled. Once this has happened, the orifices are no longer suitable for the extrusion process.

From this brief description of the manufacture of fiber glass, it can be readily seen that many difficulties would be encountered were salvaged glass used as a raw material. The elimination of contaminants, especially tramp metal and dirt, would be essential. Removing these two types of contaminant would be a costly and arduous task, especially if the glass is salvaged from unsegregated refuse. As stated previously, tramp metals would ruin the orifices. Dirt causes "seeding," carryover, and "dusting." The term "seeding" refers to the formation of a bubble in the finished glass around a particle of dirt. "Dusting" refers to the carryover of dirt and other foreign material into the furnace regenerators. The carryover material clogs and coats the refractory bricks and thereby effects a reduction in the capacity of the latter to store and to release heat. The presence of colored glass would not constitute a problem, since the basic fibers come out white. In fact, it is difficult to produce colored fiber glass.

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*Mr. Bill Webber, Process Control Engineer and Glass Technologists, Owens Corning Fiberglas, Santa Clara, Calif., 20 February 1967.

In summary, it can be stated that at present in the manufacture of fiber glass it would be difficult to use scrap glass salvaged from domestic refuse because:

1. The contaminants found in the scrap glass would be difficult to remove to the extent required to meet the high quality standards of the mix used in fiber glass making.
2. The necessary precision of viscosity control would be difficult to maintain because of the random mixture of various types of glass and the corresponding variation in chemical composition of the scrap glass.
3. Because the low cost of the basic raw materials used in fiber glass manufacture, the potential savings to be derived from substituting salvaged scrap glass would not be great enough to offset the cost of processing the scrap to the degree needed to make it suitable.
4. The fiber glass industry is a relatively low mass user of glass, and hence its consumption of glass scrap would be correspondingly limited.

Economics: The problem to be solved in the economic phase of glass salvage rests mainly in trying to offset the cost of transportation, accomplish a fairly complex processing and contaminant removal operation, and obtain some small profit in view of the low cost of basic raw materials used in glass manufacture. The basic costs range from $10 to $15/ton. Thus, it becomes apparent that technical factors exert a greater influence on the use of glass scrap than do economic considerations.

Rubber.

Sources: Discarded automobile tires constitute the major source of scrap rubber. An idea of the magnitude of the contribution from old tires may be gained from the fact that in 1962 approximately 360,000 tons of rubber, about 16 percent of the total rubber consumption, came from discarded tires. In addition to the scrap rubber generated in the rubber goods factories (some of which are recycled into the plants' production system), the remaining rubber scrap is obtained from articles which have outlived their original usefulness. Examples of such items are hot water bottles, rubber gloves, surgical wear, golf balls, etc. Large volumes of specialty scraps in the form of rejects, cuttings, and mold flushings are available from the manufacturers of various rubber products. Scrap rubber separated in automobile processing is not suitable for reclaiming because of excessive contamination, especially with metals. (E.g., Prolerization process.)

Collection and Processing: Both natural and synthetic rubbers are collected and processed together since no distinction is made between the two with respect to scrap. Thus, the original fears of an increase in complexity of the scrap rubber handling because of the advent of synthetic rubber failed to materialize.

Specialty scraps are collected from the producers by scrap rubber dealers, usually under regular service contracts. The dealers prepare the scrapped rubber for shipment to the various rubber reclamation plants which are located around the country. Scrap rubber originating in homes, garages, and farms is gathered by collectors and peddlers who sell their accumulated rubber stock to local or regional waste material dealers in lots ranging from 100 to 500 lb. The dealers send the material to reclamation plants.

At the reclamation plant, the collected scrap rubber is graded into one of the following categories: 1) whole, modified whole, and nonstaining tires; 2) "peeling" reclaims; 3) synthetic reclaims and butyl tube neoprene; 4) specialties; 5) natural rubber reclaims (red and black). The reclaimed rubber, which can be revulcanized, is ground, subjected to chemical treatment, and is then processed into rubber sheets to be marketed for use in the manufacture of new rubber articles.

Uses: One of the obvious economic advantages to be gained from the use of reclaimed rubber is by way of the reduction in the amount of crude rubber needed in the production of new goods. In fact, the availability and suitability of reclaimed rubber for use in the rubber goods industry has been largely instrumental in keeping down excessive and sustained price rises in the cost of crude rubber. Some examples of the replacement of crude rubber by reclaimed rubber are as follows: Each 20-lb tire contains the equivalent of 6 lb of crude rubber. Approximately 60 percent of the reprocessed rubber is used in the manufacture of new tires. A 100-lb lot of inner tubes replaces approximately 65 lb of crude rubber; while the rubber in 100 lb of discarded hot water bottles can be used to replace 57 lb of crude rubber. Finally, from 2 to 5 lb of reclaimed rubber are used in the manufacture of each new tire. Other uses for reprocessed rubber are found in the manufacture of automobile floor mats, windshield mounting strips, rubber hose, rubber inner soles, heels, motor mounts, and various molded and extruded items.

Many advantages of a technological nature accompanying the use of reclaimed rubber in the manufacture of new rubber goods. Reclaimed rubber can be mechanically masticated more rapidly than can crude or most synthetic rubbers, and is well adapted to the absorption of fillers. Because of these characteristics, mixing time is shortened, and consequently a saving in time and power is accomplished. Reclaimed rubber may also be extruded and calendered into sheets and embedded in fabrics more rapidly than raw rubber. Vulcanization is completed more quickly and shrinkage is less than occurs with raw rubber. Because it contains filler, reclaimed vulcanized rubber is less thermoplastic and more firm than natural rubber. Reclaimed rubber is uniform in quality and can be easily modified to meet a wide variety of requirements.

Processing the Discarded Tire: A tire is about 80 percent rubber and 20 percent fiber in its composition. The fiber consists of nylon, rayon, or cotton. It is salvaged and sold for specialty uses, as for example to the oil drilling industry for use in preventing loss of oil drilling muds. Another use is in the fabrication of light-weight concrete structures. Here it serves to retard the "set" and to retain moisture, therefore helping to improve the "cure" and reduce shrinkage, and thereby increasing the tensile strength of the concrete. The bead wire in tires cannot be economically salvaged since it is coated with rubber, which must be burned off before the wire can be used.

A relatively recent difficulty encountered in the use of reclaimed tire rubber in the manufacture of new tires is in the form of government regulations. Tires for government vehicles must be manufactured according to government specifications. These explicity exclude the use of reclaimed rubber.

Economics: The economics of rubber salvage, especially of tires, varies according to locale. The Midwest Rubber Company's St. Louis facility* pays $14/ton FOB processor's yard for waste rubber. An area having a radius of 600 miles is combed for raw materials to meet the company's commitments. On the other hand, the price paid in the Los Angeles market is $7.50/ton FOB processor's yard. The difference in price is due to the heavy demand in the former area and lighter demand in the latter. The freight charge for shipping used tires from San Francisco to Los Angeles is $9.50/ton. Some tire companies are actually paying the $4.00 (split between the freight and the broker's commission) just to get rid of their waste tires.

Plastics. To arrive at a true evaluation of the practical and economic feasibility of salvaging plastics, especially from mixed wastes, it is necessary to consider the physical and chemical nature of the material, as well as the differences between the various types, since these characteristics determine the method of processing to be used in salvage and the utilization of the salvaged material. In general, plastics fall into one of two main groups – thermoplasts and thermosets.

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*Interview with Mr. C. E. Hart, Plant Manager of the Midwest Rubber Reclaiming Company in Paramount, California, 14 March 1967.

Thermoplasts, or thermoplastic materials, may be repeatedly formed by the application of heat and pressure. Thermosets, or thermosetting materials, lose this ability to be repeatedly reformed; instead, upon being subjected to heat and pressure are converted into hard, rigid solids. An intermediate product may be formed by "vulcanizing" or "wiring" thermoplastic material. The state of this type of product may range from "rubbery" or "elastic" to a rigidity comparable to that of thermosets. The majority of household plastics are made from thermoplastic materials. The thermoplast may be likened to a super-cooled liquid rather than a true solid. Structural characteristics of the thermoplasts range from amorphous (polystyrenes) to the completely crystalline. The majority of the thermoplasts fall somewhere between these extremes. In general they tend to distort under their own weight at temperatures from 150° to 250°F. The permissible temperature maximum is lower at high stresses.

Because of their molecular structure (cross-linked network with molecular chains bonded to one another at the points of intersection), thermosets are difficult to deform either by heat or by chemical solvents. The maximum temperature at which thermosets will retain the properties pertaining to their use ranges from 300° to 450°F at continuous exposure. The upper limit at which they can withstand even mild stress is 450°F.

Uses: As is the case with the utilization of salvaged materials by any industry, a distinction must be made between industrial and "inhouse" salvage and salvage from refuse. Plastics discarded as rejects, trimmings, etc. during the course of the fabrication of plastic articles generally are clean and ready for reuse with a minimum of processing, and limitations on the range of their applications are not great. On the other hand, plastics from mixed wastes, especially domestic refuse, are contaminated, heterogeneous in composition, and generally limited as to reuse.

Because of the economic and technical difficulties involved, no significant amount of salvaging of plastics from mixed refuse has been practiced. If the contaminants could be removed and the plastics could be separated at least with respect to thermoplasts and thermosets, then the reclaimed plastic could be put to much the same use as corresponding industrial salvage.

In mixed wastes, thermoplasts are intermingled with thermosets. The two types cannot be used as a mixture because the properties of either type renders its mode of processing incompatible with that of the other. Articles composed of thermoplasts can be remelted, reworked, and formed into articles different from their original forms. On the other hand, articles of thermosets cannot be so treated.

Inhouse thermoplastic wastes are readily recovered and often after due sorting and reworking reused in the plant in which they were produced. Those which are not reused in the plant are used for noncritical applications by other manufacturers. Scrap from injection molding is in the form of "sprues" and "gates," short moldings, rejects, and "nozzle lumps." The last named items have the lowest value as scrap. Fabrication by vacuum forming results in the production of large quantities of scrap in the way of trimmings discarded in the finishing operations. The machine prunings, which are generated in the extrusion process, have little value. Film, both rejected and scrapped new film, is becoming an increasingly important source of raw material. A considerable amount of old film scrap is obtained from the salvage of polyethylene film, bags, and containers.

Uses for reclaimed thermosetic plastics are limited. Laminated stock may be ground and used for filler, compounded for fertilizer, and some may be reused for brake and clutch linings. In the fabricating plant, scrap, powder spillings, or overflow from the preform presses are collected and combined with ground excess and reject preforms of the similar material and then are reused in noncritical applications. Recently work has been done on the use of salvaged plastic in reinforced concrete [84]. The addition of plastic (8% to 16% wt. of cement) introduces a large number of potential variables such as effects on hydration rate, adhesion, elastic properties, workability, air entrainment, and chemical reactions. However, the reported research was done with the use of uncontaminated plastics, and hence it is difficult at this time to estimate the future use of reclaimed plastics in this application.

Processing and Marketing: Substandard virgin materials are produced in considerable quantity. Since they cannot be sold in the originally intended market, they can be classified as reclaimable wastes. The material is marketed at a reduced price — usually on a contract basis, to approved processors. The latter blend, compound, or color the material according to the needs for its intended use.

Plastic reclaimed from selected industrial salvage is cleaned and freed from contaminants. It is purchased by dealers from plastic fabricators. The dealer has the material ground, melted, screened, blended, and pelletized. Color may be added as needed.

Salvaging plastic from domestic wastes poses quite a problem technically because of the heterogeneity of the wastes. A possible method would be to separate the thermoplastic materials from the thermosetting by melting out the former. A difficulty to be overcome, however, is that even melted, the plastic will not flow. Hence some means would have to be sought for removing the viscous mass. The use of steam, hot air, or vacuum might serve the purpose. Another method would involve the use of solvents to dissolve specific polymers. The polymers could be recovered from the solution. Unwanted chemical constituents could then be leached or eluted from the material, leaving the purified salvaged plastic. Short-chain polymers might be recovered from thermosetting plastics by pyrolytic distillation.

Conclusions: At present, the prospects of the extensive use of salvaged plastics in the plastic industry seems to be rather dim. Factors contributing to this less than favorable outlook are as follows:

1. Low Selling Price of the New Plastic Material: New plastic stock is sold for 10 to 20 cents per pound, a price which leaves very little margin for expenditures on salvaging. The margin is materially reduced by the fact that the reclaimed material must be sold at three to four cents per pound less than is the fresh stock. Moreover the market is more limited, since the range for possible uses is narrowed considerably. For example, cleaned and baled discarded plastic milk containers sell for only three to four cents per pound.

2. Public Health Aspects: Public health agencies forbid the use of waste plastic, or even of reprocessed rejected food containers, in the packaging of food products.

3. Need for Complete Segregation of Types of Plastics: Plastics which are not compatible in molecular structure cannot be mixed in the fabrication of plastic products. Incompatible plastics will not adhere to each other and consequently the fabrication of products becomes impossible.

4. Need to Limit Salvage to Plastics Having a Broad Application: Salvors must limit their salvaging activities in plastics to those types that have a broad range of application. Those having a limited application are difficult to sell, and at the same time expensive to store.

5. Constant Supply: A limiting condition to the plastic salvaging industry is the need for maintaining a steady supply of raw materials. This is the case because the dealer must be able to guarantee a steady supply of raw material to his customers.

Rags. Rags are salvaged by industrial salvors for use in the manufacture of fine writing paper and roofing paper. Generally, rags used in the manufacture of fine writing paper are obtained directly from textile or garment factories at which cuttings and scrap ends of cloth are collected as by-products.

Rags salvaged from refuse are of little or no use to the paper industry as such because they are a conglomeration of natural and synthetic fibers, and usually contaminated. At present synthetic fibers are not used in the paper making industry, and contaminants must be removed before nonsynthetic rag fibers can be used. Removal of the synthetic fiber and decontamination would require processing so extensive as to make economically unfeasible the use of rags collected from municipal refuse. If the use should become feasible, a possible method of recovery would be by a process in which the cotton and wool portion of the mixed rags would be dissolved out by means of chemical reagents.

Summary and Conclusions. At present, most of the salvaged materials used in the fabrication of new products consist of manufacturing rejects and of wastes generated in the production of certain products. Such materials are relatively uniform in nature and free of contaminants. Hence, they can be reused with a minimum of preparation.

The use of material salvaged from mixed or municipal refuse is declining because of economic and technical difficulties in processing them for reuse. The material almost invariably requires extensive sorting, cleansing, and processing, before it can be used in most applications. The cost of such preparations often exceeds that of new raw material.

If the prime generator of municipal wastes, the householder, could be persuaded to segregate his wastes at his home, the problems of sorting and decontamination would be substantially reduced because most of the contamination comes from the contact with contaminants in common receptacles. However, in view of less than full cooperation from all householders means of sorting other than separation at the point of origin should be sought. A mechanical separator could be installed at some central point of collection. To be economically and technically feasible, however, such a separator would have to be more sophisticated in design than the present conveyor belt-blower-vacuum systems presently available.

Even with the availability of a sufficiently sophisticated separation device, the problems involved in the use of salvage from domestic refuse would not be completely solved since there would remain those of decontamination and, where necessary, the separation from one another of materials having completely different chemical structures but possessing physical characteristics so similar as to make physical separation almost impossible. Simple washing (flotation, spraying, etc.) may suffice as a means of decontamination in most cases. However, some types of contamination are such that drastic chemical treatment would be required. With the development of effective and at the same time of economical systems of decontamination, even the complex systems might prove feasible. However, the basic raw material to be replaced or extended must have a high cost to justify the use of chemicals or any complex physical process in decontamination. The problem of sorting physically similar but chemically dissimilar materials is one which will require much research. Separation could be done chemically, but the economic problem would still remain.

A final difficulty is the one of converting the sorted and decontaminated waste to a form easy to handle and ready to use by the consumer. Generally, the consumer has only the equipment needed to manufacture his product and is not in a position to convert raw wastes to the form in which he can use it. Obviously the conversion must be done at a cost that would make the reclaimed product competitive with the basic raw material.

Probably the best approach to the economical salvage and subsequent reuse of suitable wastes would be the development of a sophisticated processing system in which a variety of valuable materials could be reclaimed. With such an approach, necessary reductions in the volume of solid waste materials could be achieved, and at the same time the lowering of expenses which would result from shared processing costs would make the salvaged raw materials a more economically attractive source of supply.

VII. ANAEROBIC DIGESTION WITH SEWAGE SLUDGE

INTRODUCTION

For many years anaerobic digestion has proven to be a highly satisfactory process for treating the settleable fraction of sewage. During those years it also has become well known that other organic materials can be equally well stablized by anaerobic digestion; and in fact, a sizable portion of the domestic garbage output is so treated in a dual disposal system – garbage and sewage. However, no significant attempt has ever been made to expand the dual disposal system to include organic components of refuse other than garbage, such as for example, wood and paper. In dual disposal, as it is generally practiced, the garbage is introduced into the sewers by way of the home garbage grinder. In most of the new subdivisions, all of the homes are equipped with garbage grinders, and as a result the garbage of entire communities is treated in their sewage treatment plants. In a few communities, the garbage either is ground up at central grinding stations and water transported or is introduced at the treatment plant itself and then treated with liquid wastes. The application of the central grinder, dual disposal, is by no means a recent development. In fact, Babbitt [85] states that as early as 1885, dual disposal of garbage and sewage was being practiced at Southampton, England. Hazeltine [86] describes a central grinding station which was functioning in 1923 at Lebanon, Pennsylvania. In a paper published in 1941, Taylor [87] reported that the city of Goshen, England was using with satisfactory results a system in which ground garbage was introduced into the treatment system at the sewage treatment plant. A similar operation at Richmond, Indiana has been reported more recently by Ross [88].

Prior to the development of a reliable home grinder, studies were concerned primarily with the effects of ground garbage on the digestion process itself. Among the early studies are those of Babbitt [85,89], Kratz [90], Bloodgood [91], and Carpenter et al. [92]. Their work was confined mostly to laboratory studies on the technical feasibility of digesting garbage solids along with sewage solids. Along with the development of inexpensive and reliable home garbage disposal units in the late 1940's and early 1950's, and the concomitant increase in their usage, came a number of studies on the effect of garbage on sewage treatment. Investigations by Cohn [93], Ross [88], and Ross and Tolman [94] were aimed at determining the extent of increase in loading rates and gross effects on sewage treatment efficiency, as well as studying the specific effects on the course of digestion and gas production as the amount of garbage in sewage increased.

Their findings with respect to garbage quantity are particularly significant and applicable to an increased load of any kind (i.e., any organic solid waste). Simpson [95] reports that there is an increase of 0.5 lb of solids per capita per day and a flow increase of 3 gpd/cap. He states that a 56.5 percent increase in raw sludge necessitates 50 percent greater digester capacity and results in increased gas production and a stronger supernatant. Greater problems with scum and grease result and more frequent pumping of raw sludge is required. Cohn [93] reports an increase of approximately 15 percent to 30 percent in BOD loading. He asserts that there is no significant effect on rate and extent of volatile solids destruction or on gas composition and amount of gas produced per gram of volatile matter. Wylie [96] recommends stage digestion as a means of obtaining a supernatant low enough in solids to permit its return to the plant influent. According to Hazeltine [86] the digestion of garbage alone produces acid conditions, but ratios of 1.5 to 3 parts garbage to 1 part sludge gives good results.

It is not surprising that little work has been done on determining the maximum garbage to sludge ratio. Investigations to date have been rightly concerned with per capita garbage to sludge ratios. However, from the standpoint of solid wastes disposal, it may prove more feasible to dispose of these wastes in one treatment plant from an area served by several sewage treatment plants.

It thus becomes important to know what sewage sludge fraction of the total solids loading is necessary to maintain good digestion conditions.

CONCEPTS AND RATIONALE

The basic rationale by which studies of anaerobic digestion of the organic fraction of solid wastes are justified may be outlined as follows:

First, an appreciable and increasing fraction of househould garbage is presently routed to the municipal sewers and is successfully degraded along with other sewage solids by presently-functioning treatment processes. Further, of all methods of handling some fraction of solid wastes, the sewage treatment processes have been most thoroughly investigated and exploited technologically. The possibility must therefore be entertained that by relatively inexpensive modification and expansion of sewage treatment plants they might be made to handle a large fraction of the organic wastes of a community — e.g., paper, animal manures, and tree and grass trimmings, as well as the entire output of garbage. If such should prove to be the case, reduction of organic matter by anaerobic digestion to a stable humus suitable for soil conditioning or acceptable in a landfill with minimum volume and minimum insult to the land might be one of the feasible alternatives in solid wastes management.

Obviously if the process is to be practical, collection of organic wastes at the treatment plant must also be feasible and environmentally acceptable. In this matter the underlying rationale is that the sewage treatment plant as a waste treatment environment is already accepted and the surface transport of wastes to it would not entail problems different than those of any other central disposal plant such as an incinerator. Furthermore, the possibility exists that present trunk sewers might be utilized to transport shredded refuse to the treatment plant or underwater fill during the night hours of low sewage flow. The research plan calls for investigation of this aspect at a later date, but the certainty that organic wastes can be delivered to the treatment site justifies first attention to the potential of the treatment process such as herein reported.

OBJECTIVES

The objectives of the work reported herein and currently under way are to: 1) determine the range of the ratios of green garbage to raw sewage sludge within which garbage can be effectively stabilized in conventional anaerobic digestion; and 2) ascertain the effect of loading techniques in maximizing this ratio.

As a part of the research needed to attain these objectives, an initial study was made in which unmixed (except during feeding) digester cultures were shock loaded with garbage. Currently, experiments are being conducted with the use of mixed and unmixed cultures to determine the extent to which the garbage-to-sludge ratio can be increased without adversely affecting stabilization in cultures acclimated to receiving heavy dosages of green garbage. As the research progresses, studies will be initiated which will be concerned with determining the feasibility of digesting refuse other than garbage — such as paper, wood chips, sawdust, tree trimmings, grass clippings, and animal manures. In these studies loading criteria in terms of gross composition and chemical composition will be evaluated relative to amount and combination of these waste materials.

In keeping with the rationale of the study, the feasibility of grinding to sewers and utilizing water transport to treatment plants will be investigated. In addition, consideration will be given to the effect of such treatment on the quality of the residual water and on the relation of the condition of the transported material to its final disposition. Eventually the research plans call for an investigation of the undersea discharge either of shredded raw refuse or of stabilized material, and for experiments concerned with the dispersion of shredded refuse in water and determining the depth at which submerged material will remain submerged.

THE INVESTIGATION

Development of Equipment and Procedures

Included with the principal activities of the investigation during the period covered by this report were preparation of the materials; adaptation of analytical methods to special experimental needs; and construction, installation, and necessary modification of the apparatus to be used in the study. In particular, many equipment modifications were required in the development of suitable mixing devices for the digesters. Among the problems encountered were overheating of incubators by internal motors, off-center drifting of stirring bars when the Mag Mix type of stirrer was used, and providing equal rates of agitation to all of the test digesters.

To make a relatively simple interpretation of the results, a uniform supply of raw material, green garbage, was provided by collecting an amount of the material sufficiently large to last throughout the experimental runs, and by preparing the material(in the manner described below) for indefinite storage without deterioration.

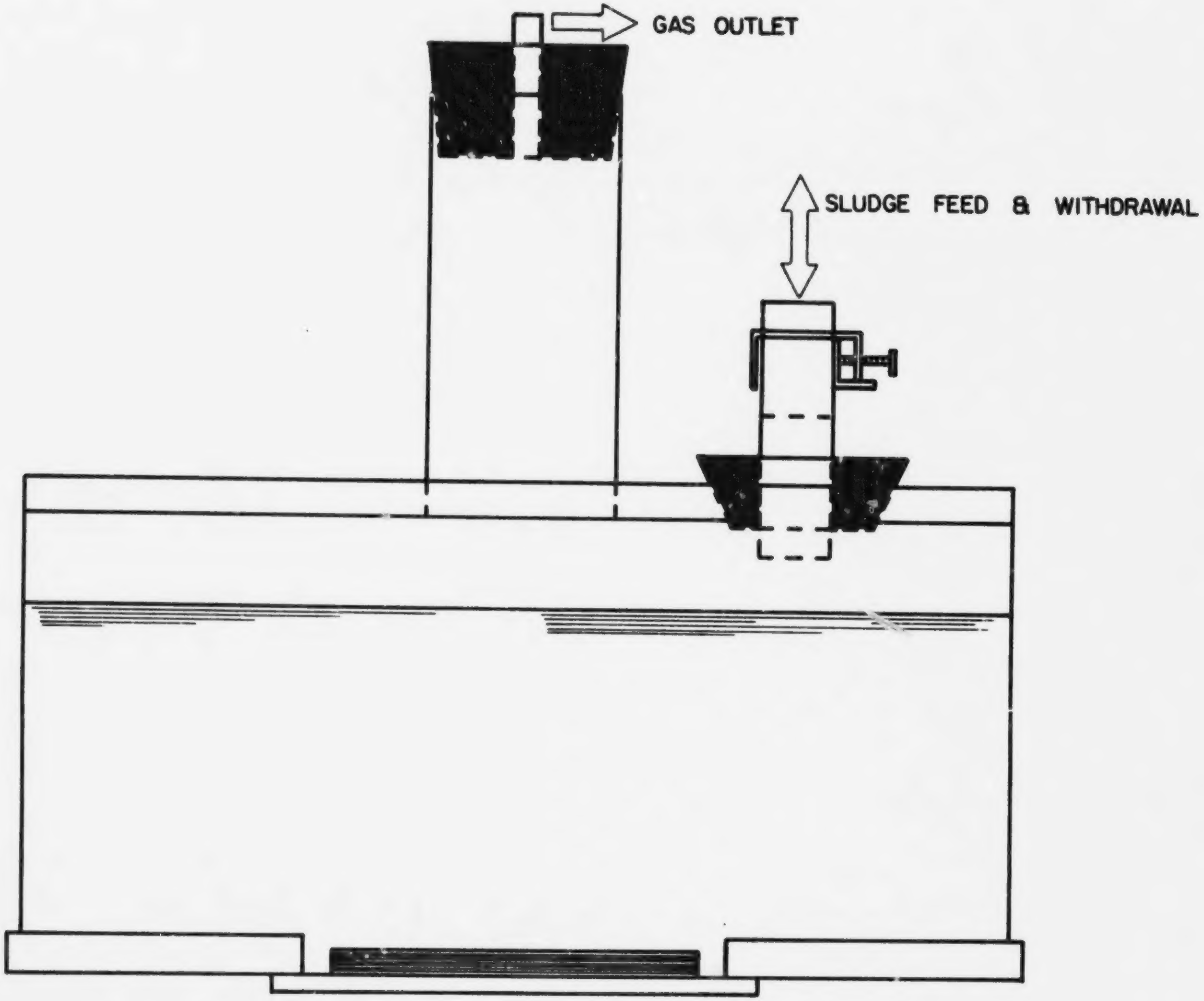
Preparation of Raw Materials. Approximately 150 lb of vegetable trimmings were collected from a local supermarket. The waste consisted predominantly of lettuce leaves, a sizable amount of cabbage, and smaller quantities of parsley, onion, and other vegetable trimmings. It was processed for storage with the use of the facilities of the Western Regional Laboratory of the U. S. Department of Agriculture (Albany, Calif.). In the processing the material was finely chopped, steam blanched for 1.5 min, and dehydrated for 1.5 hr at 160°F, 3.0 hr at 140°F, and 16.0 hr at 100°F until it was reduced to less than 1 percent moisture content. The steam blanching served to deactivate enzyme systems — a standard procedure in the preparation of frozen and dehydrated foods. The dehydrated material was then ground to a fine powder in a hammermill and the powder was stored in polyethylene bags.

As a result of the dehydration process, the initial 150 lb of wet garbage was transformed into 8.5 lb of dried material. Probably 90 percent of the loss was in the form of moisture, while most of the remainder was in the form of the unrecoverable material which adhered to the drying screens. The dried material contained 77.8 percent volatile matter, 3.04 percent total nitrogen, 54.7 percent total carbon, and 0.25 percent carbonate-carbon. Its carbon-to-nitrogen ratio of 18:1 was somewhat greater than that of primary sludge, which varies from 10-18:1.

Sewage Sludge. Seed digester sludge was obtained from the Stege Sanitary District Sewage Treatment Plant (El Cerrito, Calif.). Usually a quantity of primary sludge, sufficiently large to last from two to three weeks of experimentation, was collected (from the Stege plant) and prepared at one time. The sludge was prepared by homogenizing it in a Waring blender for 30 sec. It was adjusted to the desired volatile solids concentration with the addition of a suitable amount of tap water. The blended material was stored at 2°C until used.

Digester Units and Ancillary Equipment. One-gallon glass jugs served as digesters in those experiments in which mixing was not required. Each jug was provided with a gas outlet line which was passed through a holed rubber stopper and on to a collection vessel.

Four especially designed digesters were equipped with stirring devices. These units, one of which is schematically sketched in Figure 16, were constructed of Lucite, were cylindrical in shape, and had a depressed center well 3 in. in diameter. A 2-1/2 in. long magnetic stirring bar was placed in each well. The arrangement of well and bar was intended as a means of preventing off-center drift of the stirring bar. As stated earlier, this drift of the bar is a recurring problem when a material as viscous as sewage sludge is mixed. As is shown in Figure 17, the stirring system consisted of a mandrel-pulley arrangement powered by an electric motor (one-eighth horsepower, d.c.) equipped with a speed controller (Minarik). To prevent a buildup of heat in the incubator, the motor was installed outside the incubator and was connected by a flexible drive shaft to the master ball-bearing



GAS OUTLET
SLUDGE FEED & WITHDRAWAL

FIGURE 16. EXPERIMENTAL DIGESTER

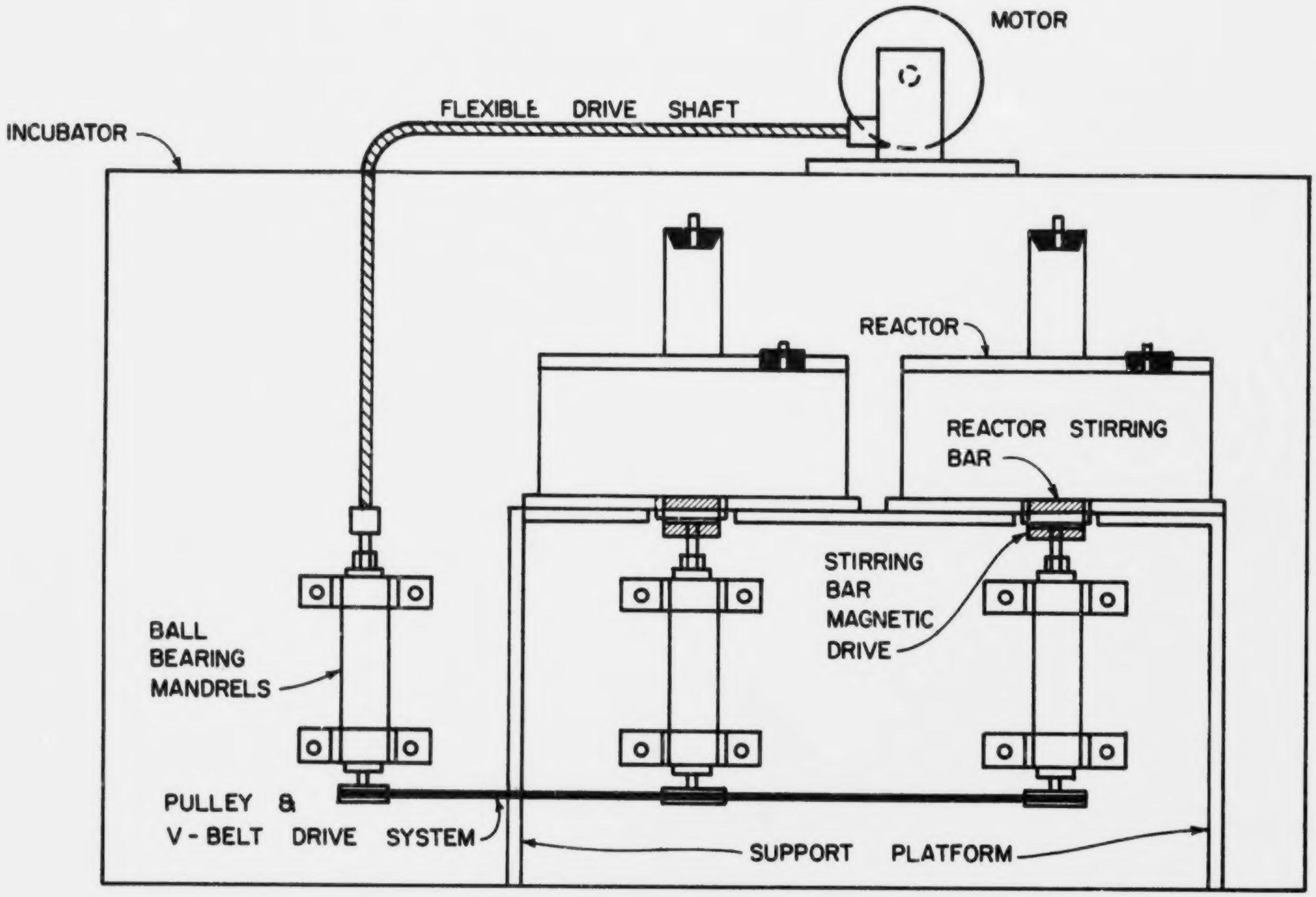

MOTOR
FLEXIBLE DRIVE SHAFT
INCUBATOR
REACTOR
REACTOR STIRRING BAR
STIRRING BAR MAGNETIC DRIVE
BALL BEARING MANDRELS
PULLEY & V - BELT DRIVE SYSTEM
SUPPORT PLATFORM

FIGURE 17. STIRRING DEVICE LAYOUT

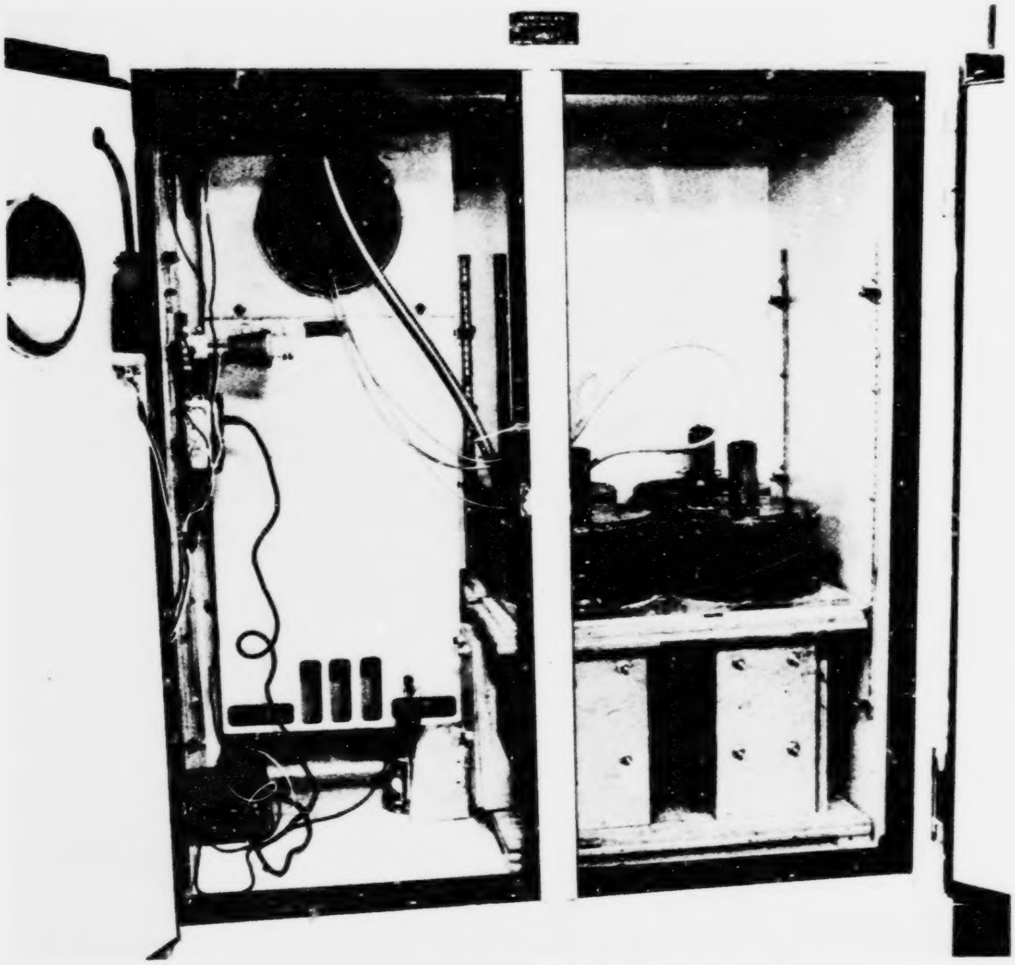


FIGURE 18. INCUBATOR CONTAINING FOUR DIGESTERS

mandrel located inside the incubator. Each of the four drive-mandrels had a 2-1/2 in. magnetic stirring bar attached to it, and each mandrel shaft was positioned directly below the center well of a digester unit. Thus, agitation of all four digester units could be controlled and maintained at equal rates. A general view of the digester arrangement in one of the two incubators in which the digesters were maintained is shown in Figure 18.

Gas Lines and Collectors. The four Lucite digesters were equipped with stainless steel lines (1/8 in. in diameter) to eliminate gas diffusion and to reduce wall action as the gas moved from the digesters to the collectors. Rubber tubing served as gas lines for the 1-gal glass jug digesters.

Two types of gas collectors, shown in Figures 19 and 20 were employed. In Figure 19 the liquid displacement type is shown. It consisted of a 5-gal glass carboy containing red-dyed 2 percent H_2SO_4 solution. The acid solution was used to prevent the absorption of the CO_2 by the liquid. Gas entered the liquid displacement collector through a glass tube which extended to within 2 in. of the carboy bottom and forced liquid to be discharged through a bottom outlet. Daily

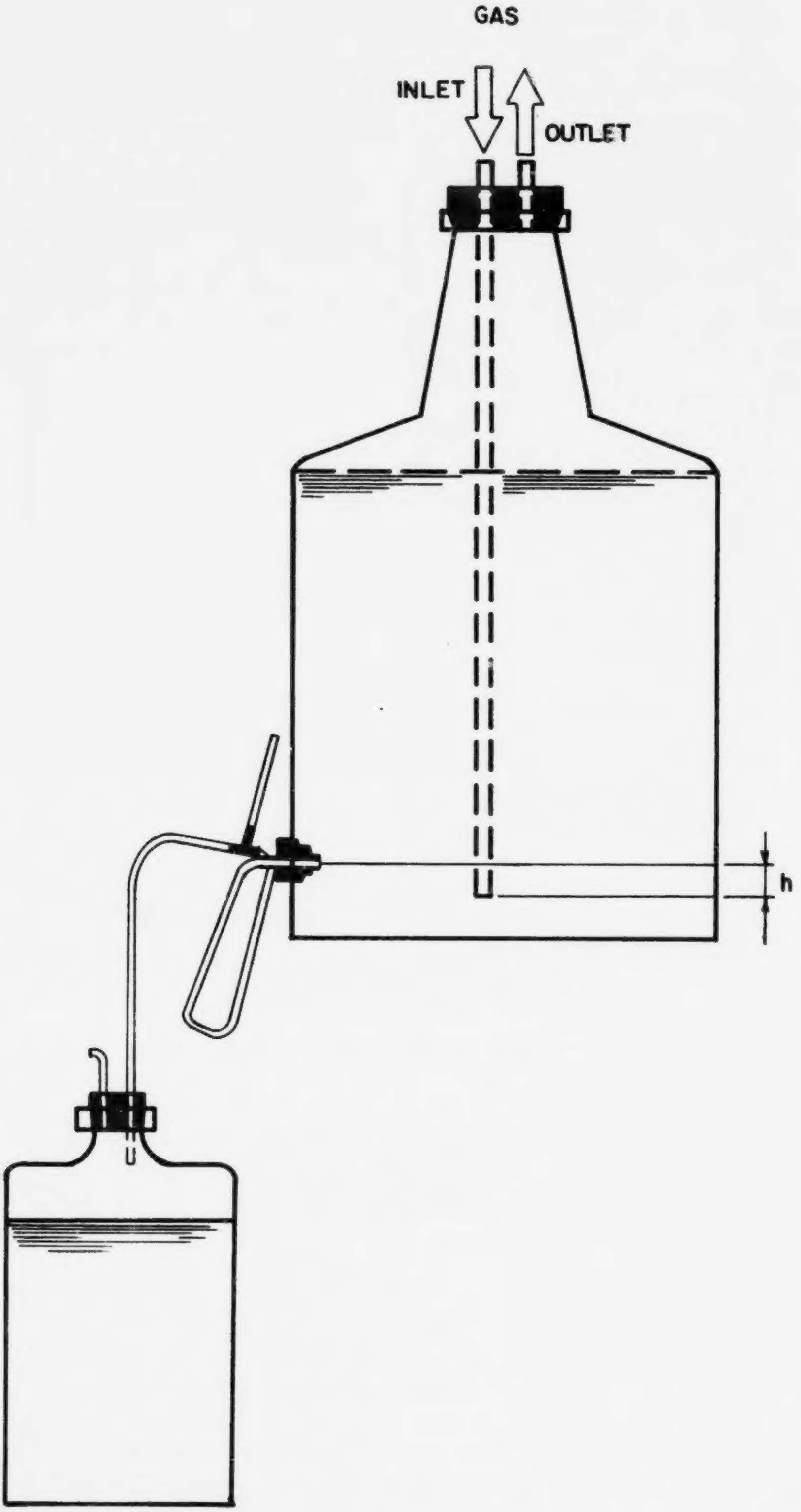

GAS
INLET
OUTLET
h

FIGURE 19. LIQUID DISPLACEMENT GAS COLLECTOR

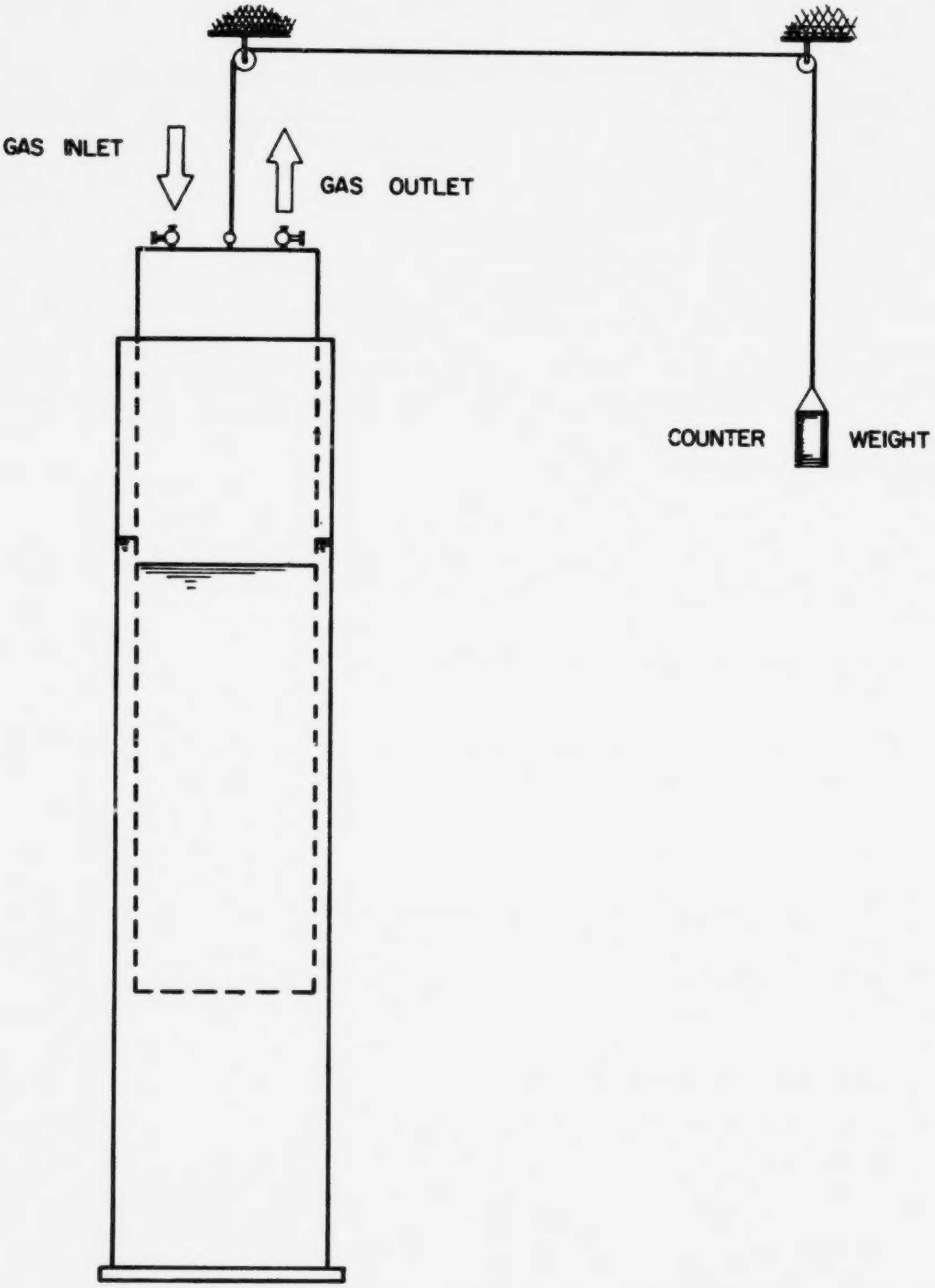

GAS INLET
GAS OUTLET
COUNTER WEIGHT

FIGURE 20. INVERTED TUBE GAS COLLECTOR

gas production corresponded to the volume of liquid discharged into 9-liter receiving carboys.

Eight gas collectors of the inverted tube type also were employed (see Figure 20). Each of these consisted of an inverted cylinder telescoped into a larger cylinder containing acid-dye solution. Counter weights relieved back pressure as gas filled the center tube and volumes were read directly from wall calibrations. A general view of the gas collection arrangement near the large incubator is shown in Figure 21.

Analyses

Total and Volatile Solids. In determining the total solids content of the sludge, 25-ml aliquots of the material were placed in tared evaporating dishes. The samples were then evaporated to dryness on a steam bath, placed in a 150°C oven for 1 hr, and subsequently were cooled and weighed. The volatile solids content was then determined by igniting the dried sample for 1 hr in a muffle furnace at 600°C. The calculation of percent volatile solids destruction is as follows:

$$D = \frac{V\ in \times V\ out}{V\ in - (V\ in \times V\ out)} \times 100$$

in which D is the percentage of volatile solids destruction and V is the volatile solids concentration. Weighing accuracy was to the nearest mg on a Mettler balance.

Volatile Acids. The column partition chromatography method described in Standard Methods [97] was used in making total volatile acid determinations.

Gas Analysis. Sludge digester gas was analyzed for CH_4, CO_2, N_2, and O_2 by the gas chromatographic method as presented in Standard Methods [97]. A model A-90-P3 Varial Aerograph equipped with a gas-solid adsorption column and a thermal conductivity detector was used to analyze the gas samples, which were injected with a stream of helium carrier gas.

Alkalinity. Alkalinity was measured by titrating 20-ml aliquots of digester supernatant with 0.02 NH_2SO_4 to the proper pH. This value was determined for a given sample type by plotting a pH/acid addition curve and estimating the midpoint of the HCO_3 neutralization section. Sample type varied in accordance with the garbage-to-sludge ratio of the feed, and midpoint values ranged from pH 4.08 to pH 4.65.

EXPERIMENTAL PROCEDURES AND RESULTS

Pursuant to the previously stated objectives, the first phase of the investigation was concerned with determining the effects of shock loading on the performance of digester cultures which are not routinely mixed and determining the general range of loadings that would be permissible under such conditions. This phase of the study was continued for 61 days, or the equivalent of two of the detention periods that were applied. Cultures which survived the treatment were then fed increasingly large dosages of the green garbage to determine the maximum ratio of garbage-to-sludge at which the digestion process may proceed at an acceptable rate. This portion of the investigation is still in progress, as is a similar study involving the use of mixed cultures which are presently being acclimated to receiving large dosages of garbage.

As mentioned previously, the practical implication of determining a maximum ratio rather than only a per capita ratio is that in large metropolitan areas it might be more expedient to discharge a disproportionate quantity of the garbage from

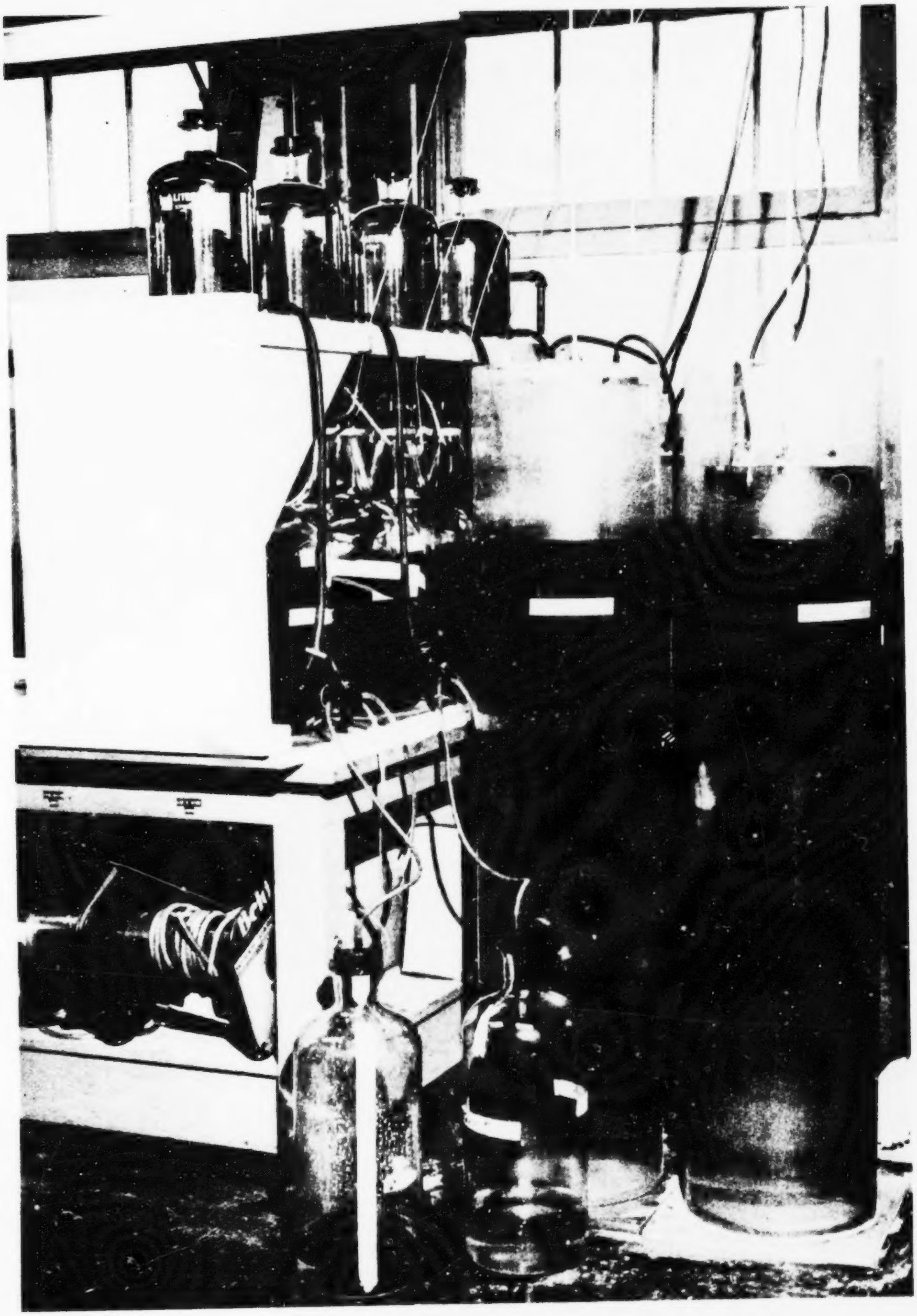


FIGURE 21. GENERAL VIEW OF GAS COLLECTING APPARATUS

a given area into one plant. Accordingly in reporting the study, indicated loadings are expressed not only in terms of per capita ratio but also as double and quadruple per capita ratios.

Procedure – Specific

To obtain five digesters which would be reasonably similar in performance, ten laboratory units were set up in the following manner: Three liters of digesting sludge obtained from the Stege Treatment Plant were placed in each of 10 one-gallon jugs. Each digester then received 100 ml of primary sludge each day over a period of two weeks. During that time the performance of the digesters was evaluated in terms of pH and gas production.

At the end of the two-week period, five of the more promising digesters were selected and the following experimental conditions were imposed upon them:

1. The temperature of the digesters was maintained at 37°C (±1°C). Digester 1 served as the control and continued to receive 100 ml primary sludge daily.

2. The composition of the feed to digester 2 was based on the equivalent of a per capita ratio of 1.68 parts green garbage to 1 part of sludge. This ratio is based on results of a study made by Hazeltine [86] in which he found the daily per capita production to be 0.13 lb volatile solids of green garbage and 0.08 lb volatile solids of primary sludge. On a percentage basis this mixture would be 62 percent garbage.

3. Digester 3 received a loading in which the garbage content was equal to double the per capita ratio or 3.24:1. In this case 76.5 percent of the dosage was in the form of garbage.

4. Digester 4 was fed garbage at a rate which was quadruple the per capita ratio at 6.5:1; that is, 86.7 percent of feed was green garbage.

5. Digester 5 received a loading that consisted entirely of green garbage.

Despite the differences in the proportions of garbage to sludge, the volatile solid loadings to all of the units were identical, viz., 3.68 grams per 100 ml. Individual batches of primary sludge feed were adjusted to this concentration in order to maintain constant loading throughout the run. Thus, the feed composition and quantity of each component delivered to the units daily was as listed in Table 41.

TABLE 41

DAILY FEED COMPOSITION

Digester	Garbage			Primary Sludge		H_2O (ml)
	% of 3.68 g	Vol. Solids (g)	Total Sol. $\left(\frac{\text{Vol. Sol., g}}{0.778}\right)$	%	ml	
1	0	0	0	100.0	100.0	0
2	62.0	2.28	2.93	38.0	38.0	62.0
3	76.5	2.81	3.62	23.5	23.5	76.5
4	86.7	3.19	4.10	13.3	13.3	86.7
5	100.0	3.68	4.72	0	0	100.0

Based on this schedule of feeding the theoretical detention time was 30 days and the volatile solids loading per day was 0.077 lb/cu ft of digester capacity.

No attempt was made to acclimate the units to garbage, and the doses described in Table 41 were administered from the first day. The green garbage was weighed and then rehydrated several hours before being fed to the units. When this was not done the relatively light dehydrate tended to float to the surface of the digesters. As a precautionary measure the refrigerated primary sludge was warmed to room temperature before feeding time to avoid severe temperature changes in the digester sludge.

Digester performance was evaluated by measurements of pH, gas production, gas composition, and total and volatile solids reduction. Frequent determinations were also made of total volatile acids and alkalinity.

Results

Volatile Acids. The relation of garbage loading to volatile acid production in the five digesters is indicated by the differences between the slopes of the curves shown in Figure 22, in which the volatile acid production in each of the digesters is plotted as a function of time. As the curves indicate, acid production was highest in digesters 4 and 5, digesters which received the heaviest loadings of garbage. On the other hand, acid production was lowest in digester 1 – the one which received no garbage. The phenomenon of increased acid production accompanying an increase in garbage loading reflects the disproportionate carbohydrate content of the garbage as compared to that of sewage sludge. The carbon to nitrogen (C:N) ratio of sewage sludge varies from 10-18:1 [86]; whereas the range for vegetables is from 14-27:1 [98]. According to an analysis made of the material used in the experiment, it had a C:N ratio of 18.1:1. In the digestion of a feed consisting solely of garbage, as was the case with digester 5, the breakdown of carbohydrates to CO_2 H_2, alcohols, and fatty acids favors the acid producing bacteria, probably due, in part, to their short generation time. Consequently, acid was produced more rapidly than the more slowly growing methane organisms could utilize them.

Judging from the cessation of gas production, the cultures in units 4 and 5 failed to survive longer than two weeks, i.e., after the acid level reached a concentration of 4000 mg/ℓ. The acid content of those units which survived never exceeded 1550 mg/ℓ, and judging from the methane production, it never was high enough to appreciably inhibit CH_4 production.

Gas Production. The rate of gas production as a function of time and garbage loading is shown by the curves in Figure 23. According to the figure, within a few days after the initiation of the feeding program gas production declined drastically in units 4 and 5, the units receiving the heaviest loadings of garbage. The sharp drop in gas production in units 2 and 3 from the 5th to the 10th days after starting is indicative of an initial shock response. Unlike digesters 4 and 5, the cultures in digesters 2 and 3 began to recover rapidly after the 10th day and later stabilized at rates approximately 10 percent lower than that of the control (digester 1). All units showed a sharp drop in gas production between days 27 and 41. Possibly some toxic substance was present in the batch of sludge used as feed at the time. The cultures recovered when a new batch of sludge was substituted.

One of the more important indices of digestion efficiency is the relation of gas production to volatile solids destruction. The relation is expressed as the ratio of cubic feet of gas produced per pound of volatile solids destroyed. Changes in the ratio (i.e., index) as a function of time and garbage loading are shown in Figure 24. The figure shows the great differences between the efficiencies of units 1, 2, and 3 and those of units 4 and 5. Within one week after the beginning of feeding, gas production in units 4 and 5 fell from an initial volume of 13-14 cu ft/lb volatile matter to 8 cu ft/lb and continued to decline until it ranged from 0 to 1.8 cu ft/lb. Gas production in unit 3 per pound of volatile matter destroyed declined to a low of 8 cu ft/lb (9th day after starting) but then recovered fairly rapidly, although not quite to the level attained in units 1 and 2.

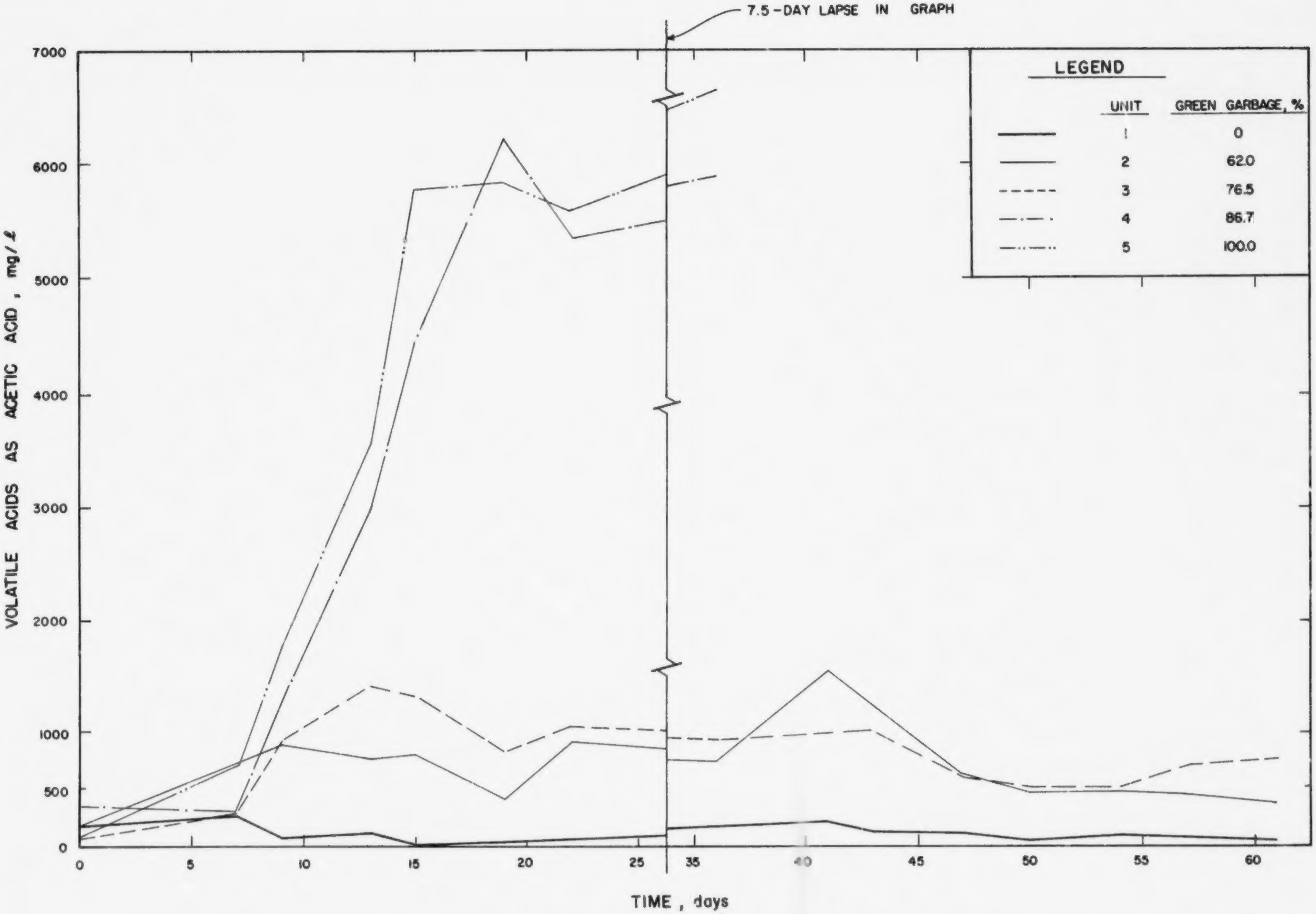


FIGURE 22. EFFECT OF GREEN GARBAGE ON VOLATILE ACIDS PRODUCTION OF DIGESTERS

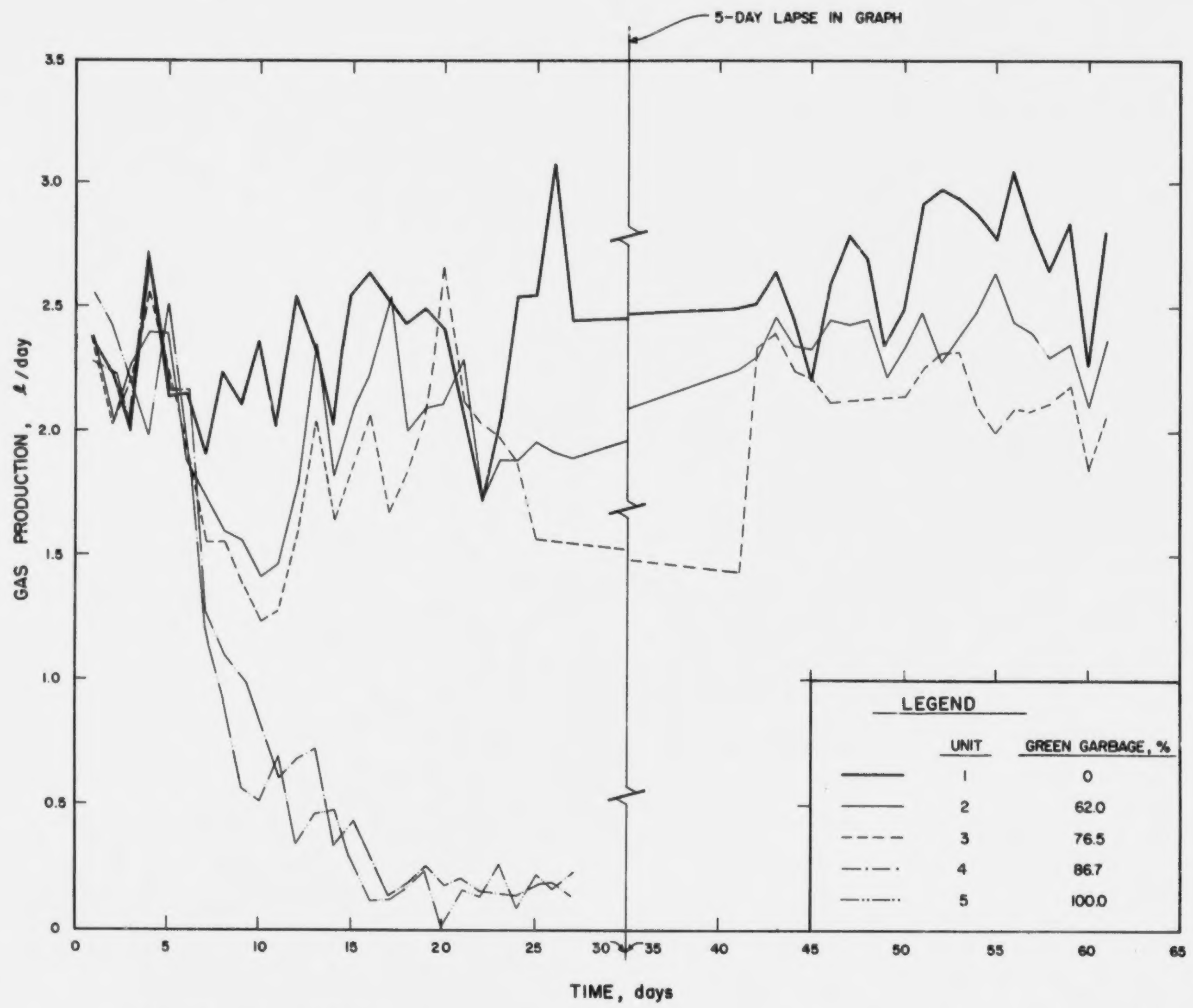


FIGURE 23. EFFECT OF GREEN GARBAGE LOADING ON GAS PRODUCTION

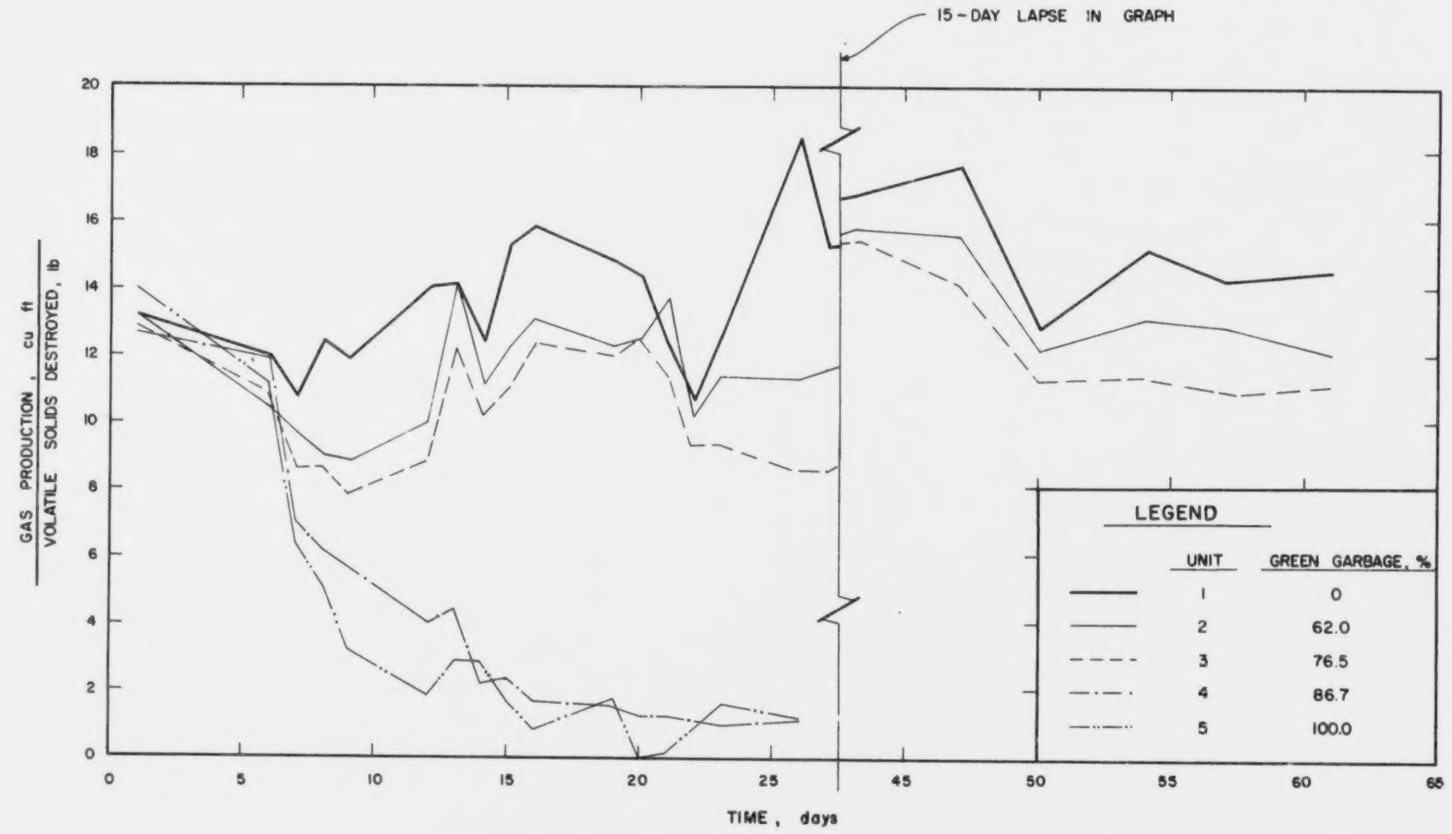


FIGURE 24. EFFECT OF GREEN GARBAGE ON DIGESTER PERFORMANCE

The level of gas production per pound of volatile matter destroyed, which was regained in units 1, 2, and 3 after the initial drop, was comparable to that characteristic of normal municipal digesters. Bloodgood [99] reports an average value of 12.1 cu ft/lb for five different treatment plants. Griffiths [100] lists values ranging from 9 to 24 cu ft/lb. However, in the experiment those digesters fed garbage apparently were less efficient in the production of gas than was the control, which received no garbage (unit 1). Thus, gas production per pound of volatile matter destroyed in unit 2 averaged only 86 percent that in the control; and that in unit 3 was only 76 percent of that in the control. These findings are consistent with those reported by Straub [101], who observed decreases of 20 percent, 25 percent, and 40 percent in units fed cabbage, carrots, and potatoes, respectively.

Gas Composition. The leakage of air into the digester gas was detected and determined by nitrogen and oxygen measurements. Results obtained in making these measurements are listed in Table 42. Obviously, some air leaked into the collectors and the plenum of the digesters, since the O_2 concentration of the gas as measured ranged from 1 percent to 6.8 percent, and no O_2 is produced in anaerobic digestion. However, as techniques were improved, leakage was reduced and the O_2 concentration was lowered to about 1 percent. Using O_2 concentration as a guideline, about 4 percent of nitrogen measured in the gas can be attributed to air leakage and the remainder to the digestion processes.

TABLE 42

NITROGEN AND OXYGEN CONTENT OF DIGESTER GAS

Day	Volume, %									
	Unit 1		Unit 2		Unit 3		Unit 4		Unit 5	
	N_2	O_2	N_2	O_2	N_2	O_2	N_2	O_2	N_2	O_2
8	11.6	3.0	15.5	3.2	13.4	2.4	17.2	3.8	21.2	4.4
13	9.6	2.4	15.7	2.5	16.4	2.8	18.7	3.6	18.7	3.5
20	8.1	1.8	17.7	3.1	12.6	2.1	34.6	6.5	28.8	6.2
27	8.1	1.6	11.2	2.3	11.9	2.3	43.9	7.2	31.0	6.8
49	9.9	1.1	10.3	1.2	10.3	1.2				
55	9.0	1.1	8.4	1.0	8.3	0.9				

The effect of garbage loading on methane and CO_2 production is shown by the curves in Figures 25 and 26, respectively, in which methane and CO_2 production is plotted as a function of garbage loading and time. As the differences in the slopes of the curves in Figure 25 indicate, methane production decreased with increase in garbage loading. Conversely CO_2 production was enhanced by increase in garbage loading. These results are consistent with the volatile acid observations.

Alkalinity. Closely associated with digestion control is the alkalinity or buffering potential of the system. The buffering capacity may come from two sources:

1. Alkalinity contained in the carriage water.

2. Ammonium bicarbonate from the normal digestion process which may be represented by the following equation:

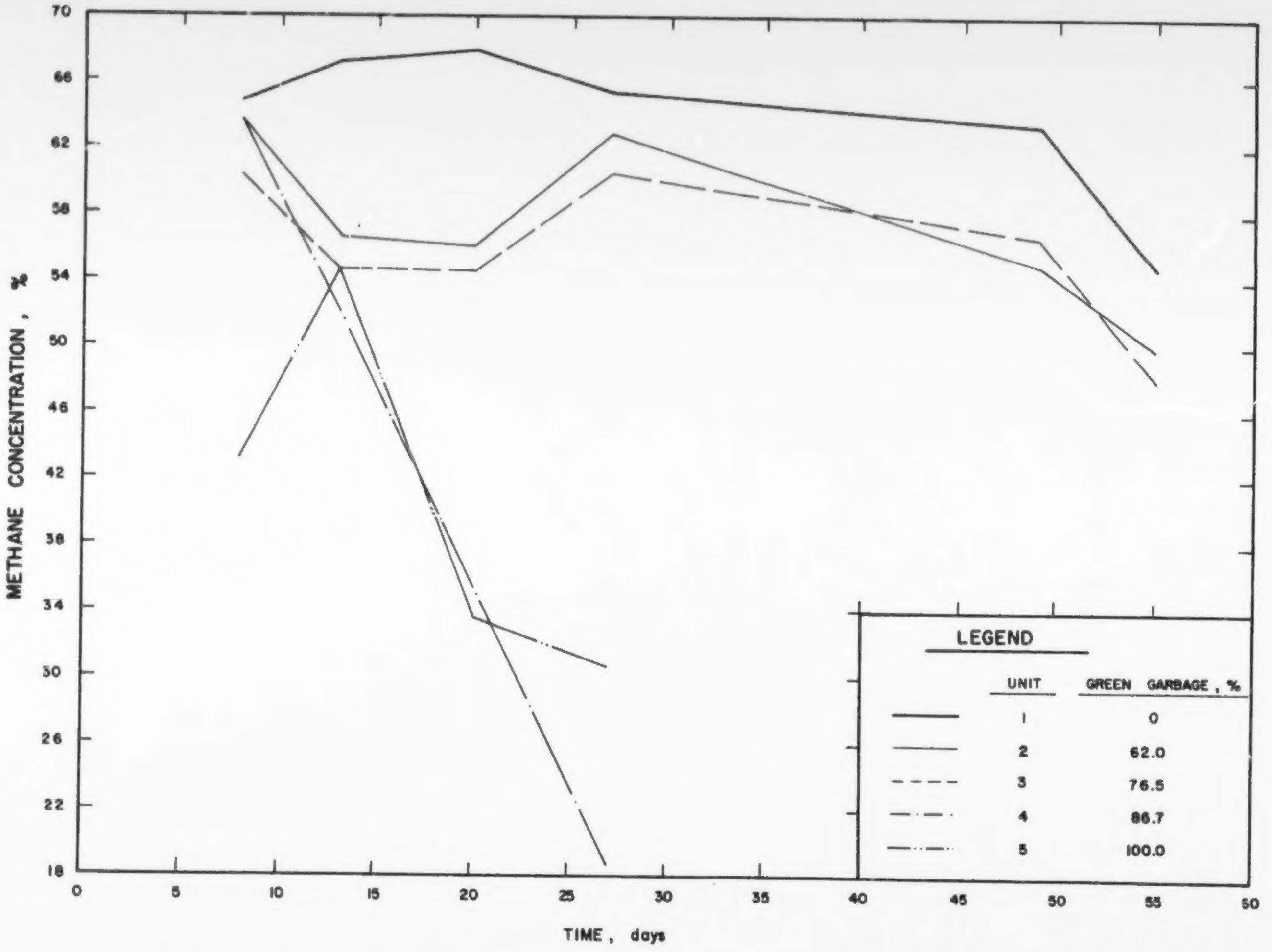


FIGURE 25. EFFECT OF GREEN GARBAGE LOADING ON METHANE CONCENTRATION OF DIGESTER GAS

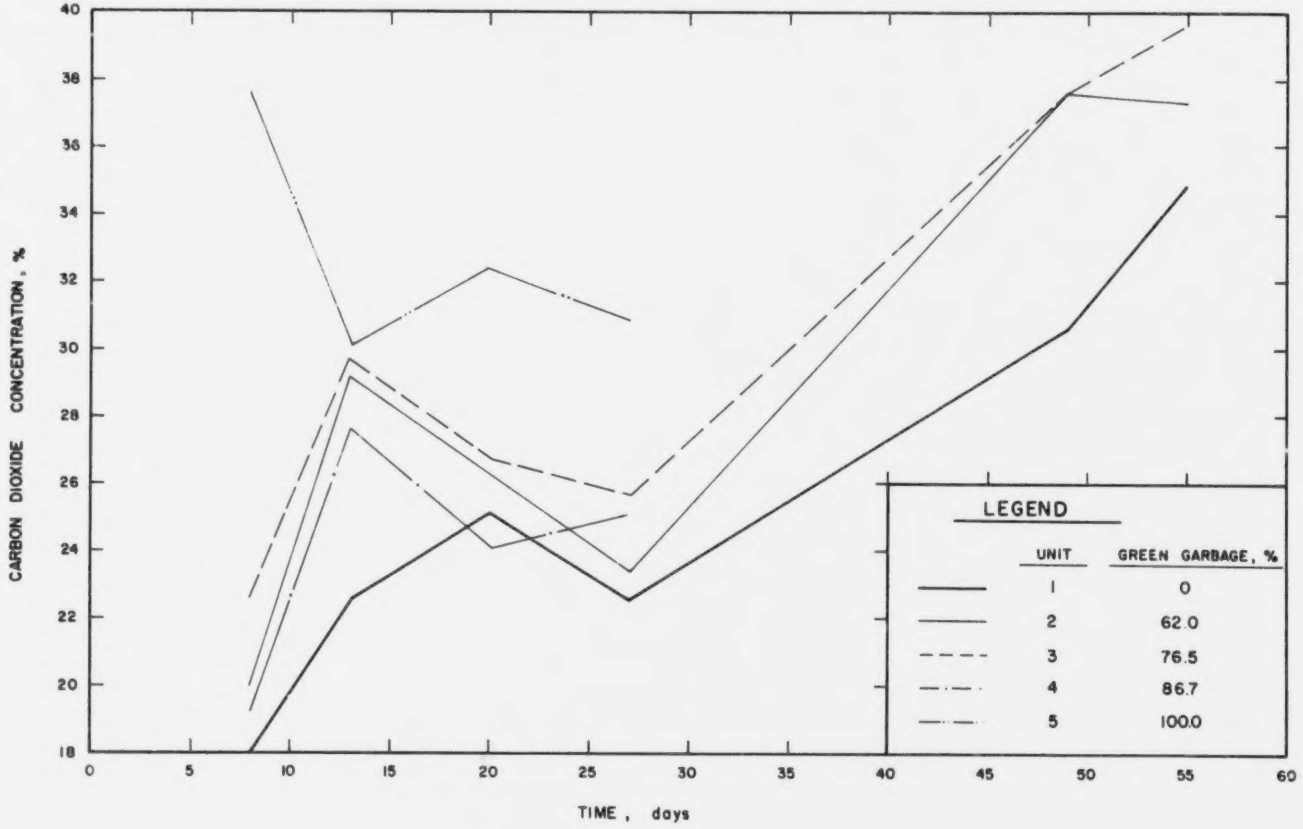


FIGURE 26. EFFECT OF GREEN GARBAGE LOADING ON CARBON DIOXIDE CONCENTRATION OF DIGESTER

$$\underset{\text{(Organic Matter)}}{C, O, H, N, S} \xrightarrow{\text{digestion}} \underbrace{CO_2 + H_2O + NH_3}_{NH_4HCO_3} + CH_4 + H_2S$$

According to Coulter [102], the ammonium bicarbonate remains in solution and contributes to the alkalinity of the substrate.

The cultures in units 2 and 3 had consistently higher concentrations of alkalinity than did the control, despite having less carriage water and a lower protein content. This is shown by the relation between the curves in Figure 27, in which the alkalinity of the various cultures is plotted as a function of time. This phenomenon must be interpreted then as indicative of an increase in digestibility resulting from the addition of garbage to sewage. Corroborative evidence may be drawn from the work of Garber [103] and Rudolfs and Setter [104] who have independently reported that increased ammonium bicarbonate production has been associated with thermophilic rather than mesophilic digestion due to more complete breakdown of proteins.

The cultures in units 4 and 5 were deficient in alkalinity probably as a result of neutralization by the high concentrations of volatile acids.

Hydrogen Ion Concentration (pH). The pH level of the cultures in units 1, 2, and 3 remained within the range of 7.0 to 7.5 with few exceptions, as is shown by the curves in Figure 28 in which the pH levels of the various digesters are plotted as a function of time. The pH levels of units 4 and 5 continued to drop sharply soon after feeding was initiated, and continued to do so until a low of 5.2 was reached on the 28th day. By this time the digesters ceased functioning for practical purposes.

The correlation between pH level and rate of gas production was quite evident in this experiment. When the pH of a digester was above 7.25, gas production generally was increased. On the other hand, a drop in pH level was accompanied by an even sharper drop in gas production. The pH levels in digesters 2 and 3 are also in keeping with the high levels of alkalinity prevailing in them.

Reduction in Volatile Solids. According to the data listed in Table 43, in which are presented values for the percent volatile solids reduction in the various digesters, from 65 percent to 80 percent of incoming volatile solids was destroyed. The difference between the average values for units 2 and 3 and that of unit 1 is too slight to be significant. In our experiments, evidence for an increase in rate of digestion in units 2 and 3, such as was observed by Bloodgood [91] to take place when garbage was digested with sludge over that of sludge alone, is to be found more in the increased alkalinities in the two digesters, than in their insignificantly higher percentage of volatile solids destruction.

Discussion and Conclusions

Results obtained thus far demonstrate that anaerobic cultures can adjust to shock loadings of garbage provided that the garbage content of the feed (garbage-sludge mixture) is not in excess of 76.5 percent of the total feed. Although those cultures which received a feed of which the garbage fraction was 76.5 percent or less of the input did survive, their efficiency dropped 40 percent during the first week after the initiation of the experimental run. It was only after the bacterial population became acclimated or a new one was developed, that the cultures resumed functioning at an efficiency comparable to that of the control. The point of minimum efficiency occurred on the tenth day, and there was every indication that

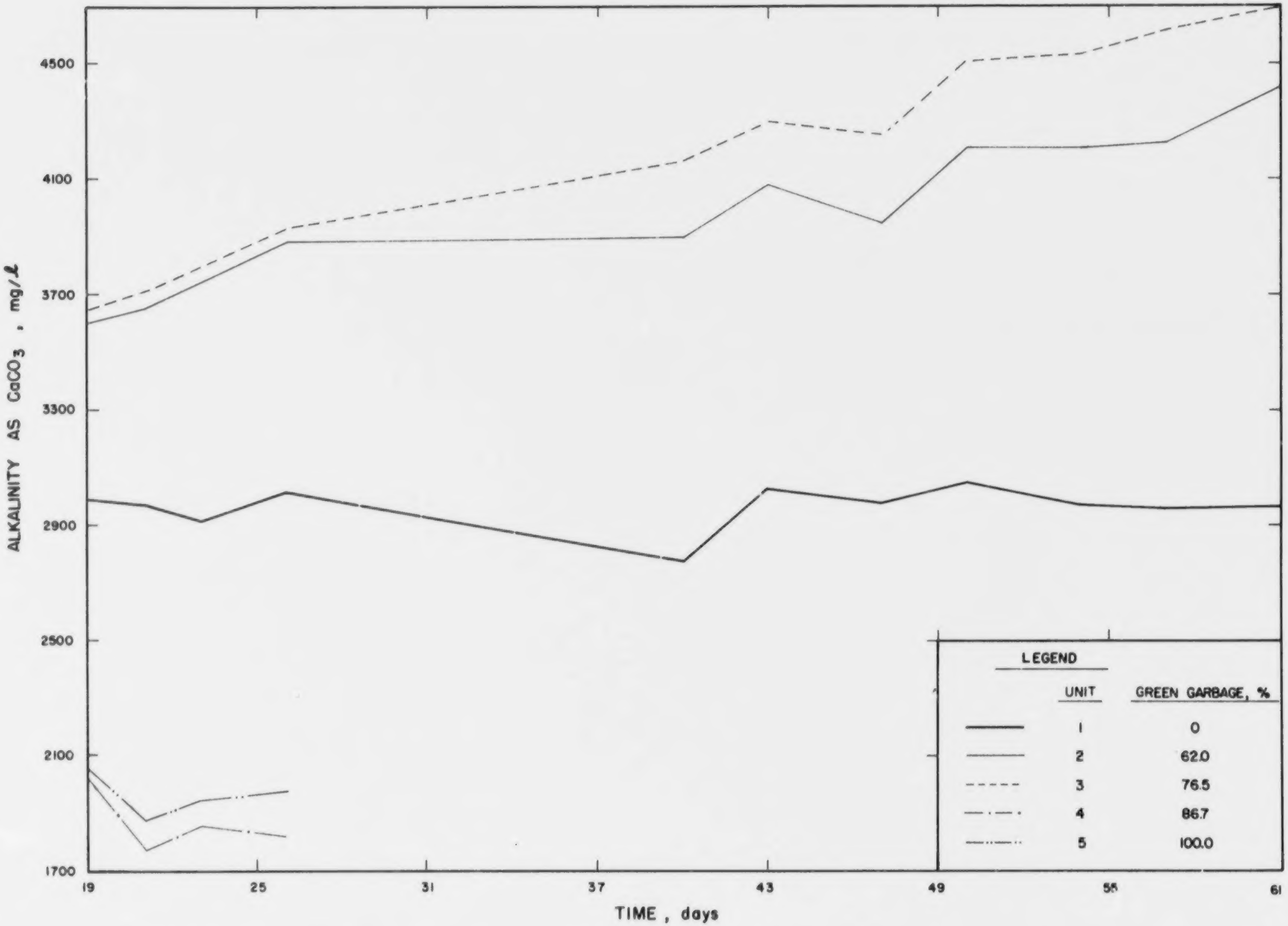


FIGURE 27. EFFECT OF GREEN GARBAGE ON ALKALINITY OF DIGESTORS

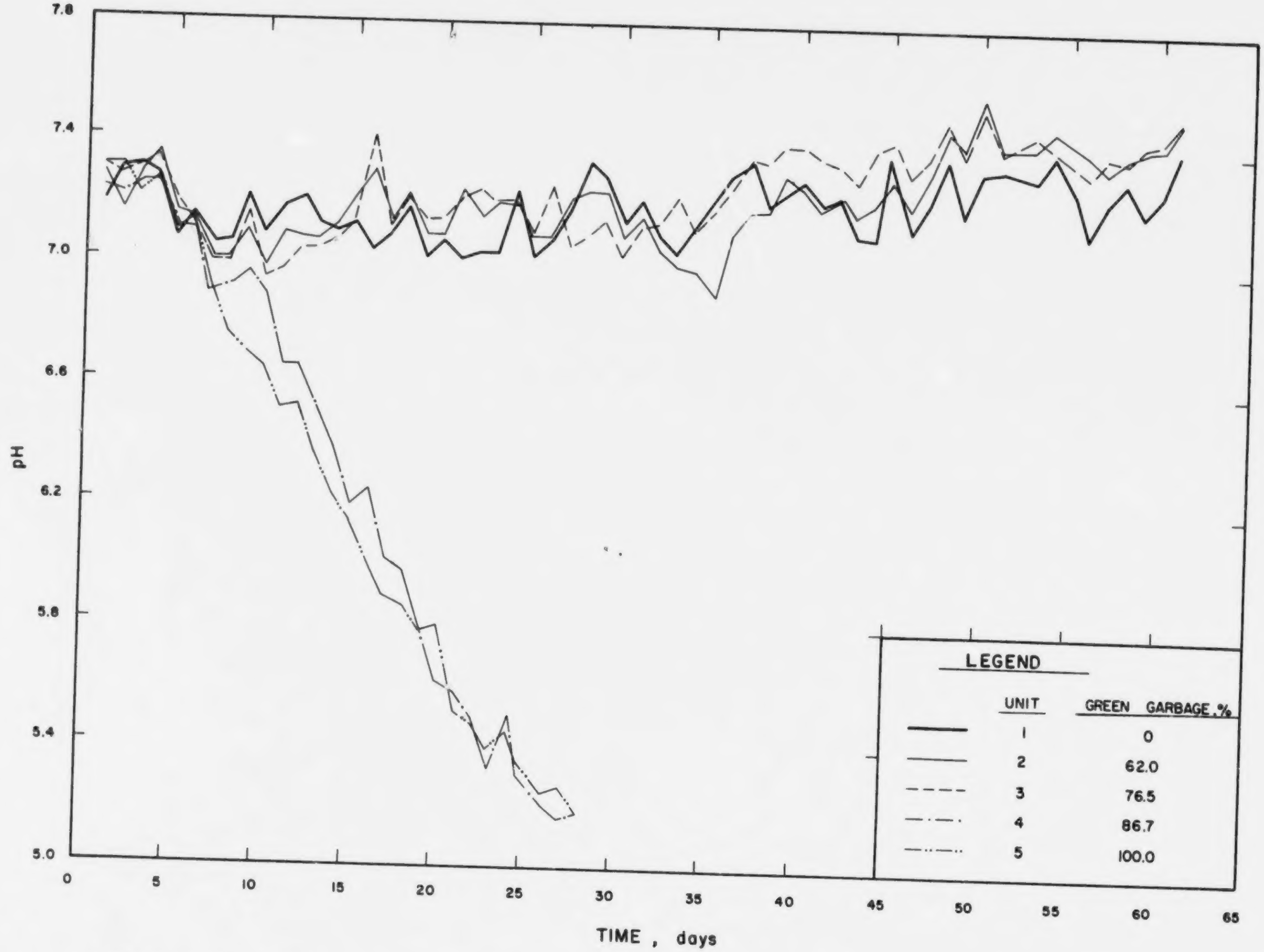


FIGURE 28. EFFECT OF GREEN GARBAGE LOADING ON pH OF DIGESTERS

TABLE 43

VOLATILE SOLIDS REDUCTION

Day	Volume, %				
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
1	79.0	79.0	79.5	78.9	79.5
6	78.4	78.9	78.2	78.9	78.8
7	78.2	78.8	78.2	78.8	78.4
8	77.8	78.3	77.7	78.3	78.2
9	77.2	78.3	78.2	77.9	76.2
12	78.8	77.8	77.7	77.3	77.8
13	71.7	72.6	72.4	72.2	72.3
14	70.5	71.5	71.5	71.0	71.7
15	72.3	72.9	72.5	71.3	71.6
16	72.3	73.1	72.2	71.0	70.4
19	72.2	73.7	73.2	69.9	69.3
20	72.5	73.2	68.3	68.2	69.9
21	72.2	72.2	72.3	68.5	67.8
22	70.4	72.9	72.4	67.5	67.6
23	71.2	72.2	72.4	67.4	66.6
26	71.8	73.4	72.2	65.9	65.8
27	69.9	70.5	71.3		
43	70.1	68.3	69.1		
47	70.3	69.1	66.8		
50	80.1	79.9	79.2		
54	79.0	79.1	76.8		
57	80.5	77.3	80.5		
61	70.9	79.1	76.9		
Avg.	74.2	74.9	74.3	72.7	72.6

the culture in unit 3 (fed 76.5% garbage) was near the critical limit of survival. Its pH had dropped to 6.8 which is considered the minimum level at which methane bacteria regeneration can proceed without inhibition. It might then be concluded that under conditions of shock loading, in which no attempt is made to acclimate the digester cultures, the maximum quantity of garbage acceptable is about 75 percent of the total input. This is equivalent to about 3 parts of garbage to 1 part of primary sludge, or double the present per capita ratio.

Other specific conclusions concerning the effects of green garbage on the digestion process which may be drawn from the results obtained in the study are as follows: (Estimations of percent reduction, changes in composition, etc. are based on results obtained with the control.)

1. There was a marked increase in organic acid content resulting from the breakdown of carbohydrates to fatty acids.

2. Gas production was reduced by 10 percent in units receiving 62 percent to 76.5 percent garbage.

3. The efficiency of digestion in terms of cubic feet of gas produced per pound of volatile solids destroyed was reduced by 14 percent for unit 2 (fed 62% garbage) and 24 percent for unit 3.

4. Gas composition was significantly altered — 7 percent less methane and 7 percent more CO_2 — which is what one would expect on the basis of the increase in organic acids. A favorable environment for acid-CO_2 producers was created by the predominance of carbohydrates in the substituted material, i.e., green garbage for primary sludge.

5. The buffering capacity of digesters was increased by garbage feeding, as is indicated by 50 percent increases in alkalinity of the test units. Alkalinity increases have been cited in the literature [103, 104] as indicative of a more complete breakdown of proteins. On the basis of the literature, therefore, it may be assumed that because the two garbage-fed digesters had a higher alkalinity than did the control, the digestibility of a garbage-sludge mixture was greater than that of sludge alone.

6. The pH of units receiving garbage rose from 7.2 to 7.4, reflecting the increased alkalinity.

7. Destruction of volatile solids was slightly greater in the test units than in the control, which is indicative of greater digestibility.

Future Work

Experiments planned for the future will be concerned with: 1) determining the upper permissible limit of garbage loading to fully acclimated digesters; and 2) evaluating the potential of the anaerobic digestion process in coping with garbage containing waste paper. Work on the first section already is in progress. Following the experiment described in the preceding sections, the surviving units, now thoroughly acclimated to receiving large dosages of garbage, were and are being fed increasingly large dosages of garbage. One of the digesters is receiving a dosage having a 4:1 garbage-to-sludge ratio, without any apparent detriment to its activities. A second one is being even more heavily loaded without ill effect; the garbage-to-sludge ratio of its feed is 5:1. Inasmuch as these two digesters have been operating efficiently during the two weeks preceding this writing, the garbage loading will probably be appreciably higher before the digesters fail.

The work involved in the second phase of the future work is considered to be of a paramount importance because it will be concerned with the disposal of paper, a material which constitutes 60 percent of the municipal solid wastes. Plans include studies in which digesters will be fed varying quantities of paper, and combinations of paper with other wastes. Parallel studies involving the use of pure cellulose will be conducted to define the kinetics of cellulose digestion.

VIII. WET OXIDATION OF ORGANIC WASTES

INTRODUCTION

Experimental work directed to the application of wet oxidation to solid wastes is based on the general concept of indirect recycling depicted in Figure 1. Under this concept certain fractions of solid wastes are subjected to special processing to produce raw materials which may then be utilized by existing or new industries for the production of consumer goods. Ideally, of course, the concept should apply to all fractions of the solid wastes generated by a community. Practically, however, only certain fractions can be economically reclaimed.

The idea that wet oxidation might be a technologically feasible wastes reclamation process derives from success in applying it to the oxidation of organic matter in liquids and from encouraging experiments in fractionating wood to produce industrial chemicals in liquid form with a residual pulp which might be used in gypsum board, formed packaging, or other low cost specialty items. It was reasoned that a process which will work on wood should be easily adaptable to paper and perhaps to the whole spectrum of organic wastes found in community refuse, including manures, tree trimmings, grass clippings and sewage sludge, as well as demolished lumber and waste paper. Nevertheless, if it could be applied to nothing more than waste paper the process would be an important new method of solid wastes management. Obviously, materials cannot be expected to be eternally recycled into the basic raw material pool. The solid fractions would themselves eventually become wastes, but if they were recycled, say two or three times, the net result would be both a net reduction in the volume of solid wastes routed to sinks or incinerators and a conservation of natural resources.

Pursuant to the foregoing general concept and specific rationale, a research team was assigned to a systematic experimental study of the application of wet oxidation in the technology of solid wastes management.

DESCRIPTION OF THE PROCESS

Wet chemical oxidation involves the combination of molecular oxygen or of atmospheric oxygen with organic material in an aqueous suspension or solution under superatmospheric pressures and at elevated temperatures. As such the process has been utilized for the disposal of water-borne industrial and municipal wastes with a consequent production of thermal energy. The energy may be recovered as steam or electricity.

Extensive reviews of the basic principles of the process have been given by Zimmermann [105,106] and Teletzke [107]. In theory any aqueously dispersed organic material can be oxidized if sufficient energy is supplied to the reaction or if in terms of the Zimmermann process, there is sufficient pressure and temperature. The critical difference between this process and conventional combustion lies in the much lower temperature at which the wet oxidation reaction occurs.

Typical equipment required for this process (shown in Figure 29) includes: a reactor, air compressor, heat exchangers, effluent pumps, and a gas expansion engine. An effluent containing organic waste material is pressurized, mixed with compressed air, and preheated in heat exchangers by heat recovered from reactor products. At about 200°C the effluent-air mixture reacts spontaneously and is introduced into the reactor. Reactor temperature can vary from 150°C to the critical temperature of water (372°C); however, normal reactor conditions are 220-320°C and 1000-2200 psig. Reactor products pass through the first heat exchanger to preheat the incoming effluent-air mixture, and are separated into a gas and liquid phase. The gases — steam, carbon dioxide, and nitrogen — are expanded to

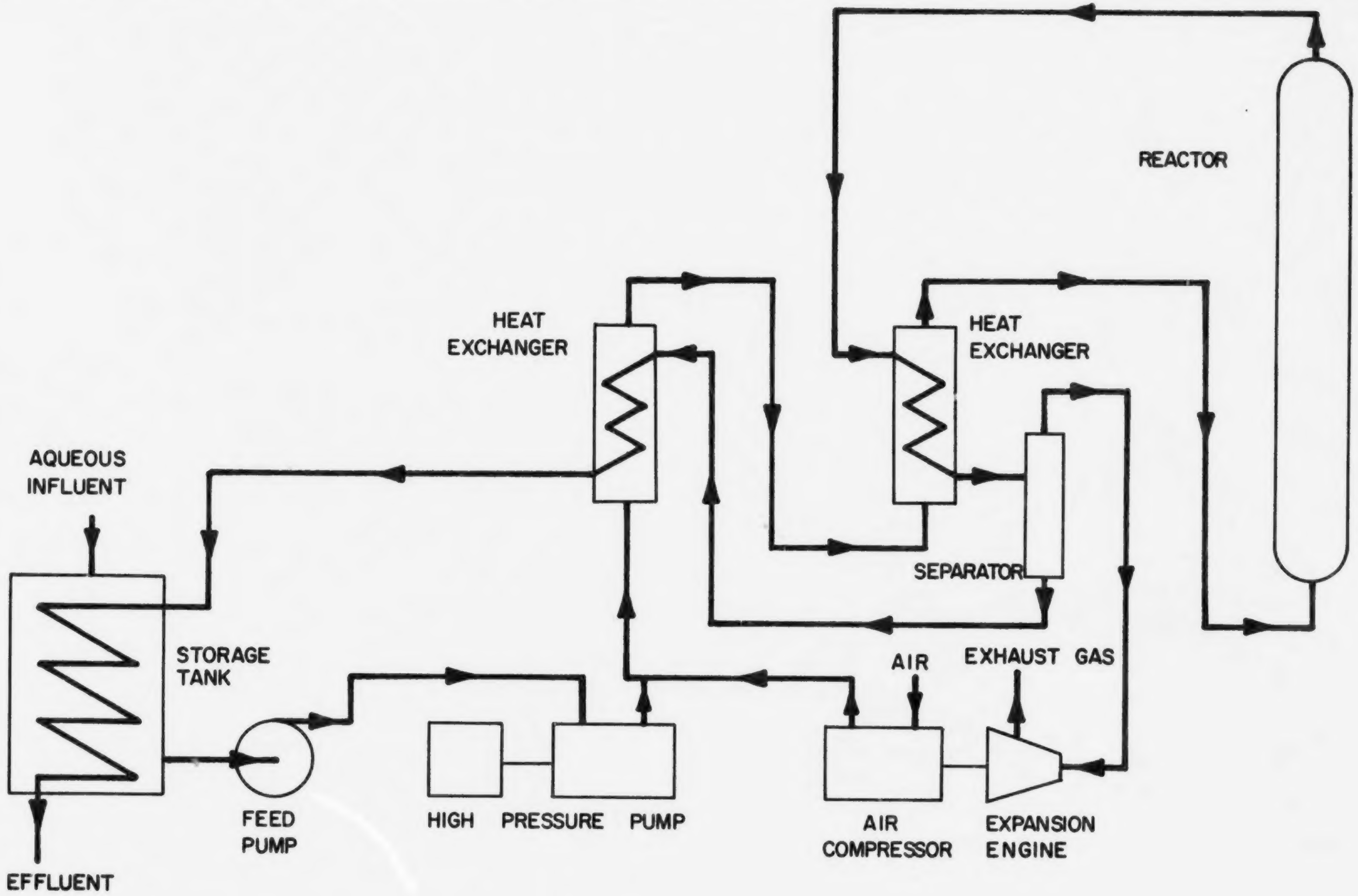

REACTOR
HEAT EXCHANGER
HEAT EXCHANGER
SEPARATOR
AQUEOUS INFLUENT
STORAGE TANK
EFFLUENT
FEED PUMP
HIGH PRESSURE PUMP
AIR
EXHAUST GAS
AIR COMPRESSOR
EXPANSION ENGINE

FIGURE 29. SCHEMATIC DIAGRAM OF CONTINUOUS WET OXIDATION PROCESS DEVELOPED BY ZIMMERMANN [117]

provide power for the air compressor and in some instances to generate electrical power; the liquid phase is used to preheat incoming effluent.

The extent of oxidation achieved by this process, expressed in terms of the chemical oxygen demand* (COD) of the effluent, is primarily determined by the temperature reached in the reaction. At a given temperature a definite amount of COD is removed. This reduction is independent of the quantity of air in excess of the stoichiometric amount required. COD reduction is very low around 100°C, increases sharply between 150-225°C,and is almost complete at 330°C. Also, at low temperatures, several hours are required to attain the COD reduction, and this reduction is at a lower level of oxidation. At temperatures of 250°C and above the reductions are attained in minutes.

Pressure indirectly determines the relationships between the other reaction variables and under a given set of conditions, the extent of oxidation. At a given temperature, the total pressure in the system must be sufficiently high to avoid excessive water loss. Oxidation proceeds smoothly only if water is present, and usually stops if it is not. At a given temperature and pressure, the air input is limited by the effluent concentration, i.e., by the amount of water that will be removed from the system. The extent of oxidation of such an effluent is determined by its heating value expressed in terms of the amount of air required.

Historical

Almost without exception, wet oxidation as it is currently being utilized is based on a process developed by Zimmermann in the early 1950's. However, the basic reaction involved, that of oxidizing aqueous suspensions or solutions of organic material with oxygen under superatmospheric pressures at elevated temperatures, and its application to organic waste materials extends back over fifty years to the work of Strehlenert and others.

Strehlenert [108,109] developed a process for the recovery of carbonaceous solids (sulfite coal) from spent sulfite pulping liquors by heating unneutralized spent liquor in the presence of air or oxygen under 20 atmospheres pressure at 200-210°C. Initially, free and chemically bound sulfite was oxidized to sulfate and then, as the cation supply was depleted, to sulfuric acid which caused the lignosulfonic acids to condense and precipitate from solution. This process was extensively modified by Strehlenert [110-114] to improve the yields and properties of the recovered solids. Although given plant-scale trials in 1916 [115] and 1918 [116], it was never utilized commercially.

Henglein and Stauf [117] patented a process in 1927 for the removal of organic impurities from aqueous solutions of metal salts by treating the solutions with oxygen under pressures greater than 1 atmosphere and at temperatures above 130°C.

Bergstrom and Cederquist [118] developed a similar process in 1937 for the removal of organic substances from spent kraft pulping liquors by heating the liquors with oxidizing agents such as air or oxygen-containing gases at elevated temperatures under superatmospheric pressures. Later Cederquist [119] noted that many organic waste materials, particularly lignocellulosic materials such as spent sulfite pulping liquor solids and peat, were completely oxidized to carbon dioxide, water, and low molecular weight organic acids, mainly acetic acid, at temperatures of 190-225°C. Technically useful reactions, particularly for the recovery of carbonaceous solids, occurred at lower temperatures and at somewhat less than complete oxidation. Sewage sludge was only partially oxidized at 225°C but the residue left by the reaction was easily filtered and de-watered. Cederquist [120] also found that the low molecular weight acids formed in the reactions of spent sulfite or kraft pulping liquors were extremely difficult to oxidize even at temperatures of 290°-295°C. Catalysts such as $CuMn(Cr_2O_4)_2$ allowed complete oxidation of these acids in both liquors at 260°C.

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*Chemical oxygen demand determined by standard dichromate reflux method.

Entrained organic material could be oxidized by adding molecular oxygen to the steam-gas mixture and passing it over this same catalyst at 300°C.

In 1954, Cederquist [121,122] patented a process for the recovery of heating values in spent sulfite pulping liquor solids by oxidizing the liquor with air or oxygen, preferably in the presence of catalysts such as Cu, Fe, or V oxides, under 25-200 atmospheres pressure at 180-300°C until the solids precipitated from solution. The heat evolved by the reaction was utilized to maintain the process; the carbonaceous solids were burned separately as fuel. This process was modified [123] to allow conversion of sulfide and sulfite in the liquor to sulfate prior to addition of a catalyst, and was extended [124,125] to include other lignocellulosic materials such as wood, sawdust, lignite, and peat.

Salveson et al. [126] developed a process in 1948 for producing vanillin from alkaline spent sulfite pulping liquor by treating the liquor with air or oxygen under autogenic pressure at 140-170°C. Shoeffel [127] patented a modification of this process which involved heating the alkaline spent liquor under 1500 psi pressure at 200°C. These processes were the bases for the process patented by Zimmermann[128,129] for the oxidation of organic waste material in industrial and municipal effluents. The Zimmermann process involved treating effluents such as spent sulfite and kraft pulping liquors, Masonite liquor, cheese plant whey, sewage sludge, or water-fuel oil dispersions with an oxygen-containing gas under 1500 psi pressure at 250-330°C. Under these conditions the process was self-sustaining and allowed the recovery of up to 95 percent of the heating value of the organic material. Thermal energy in excess of that required to maintain the process could be converted into steam and electricity. Recently Earle et al. [130] patented a modification of the Zimmermann process. The modification involves sewage sludge by heating the sludge with air under superatmospheric pressures at 100-225°C. The treated sludge has a faster settling rate and a reduced oxygen demand.

Krysinskii and Gorchakova [131] patented a process in 1955 for the removal of organic substances from industrial effluents by treating the effluents with air or oxygen at elevated temperatures under pressures greater than 75 atmospheres, and preferably under alkaline conditions.

Schmalenbach et al. [132] developed a process in 1959 for the purification of industrial effluents, particularly those from ammonia-producing coke or gas plants, by oxidizing the effluents with an excess of oxygen under superatmospheric pressures at elevated temperatures. Insoluble material was separated by deposition at elevated pressure and temperature before the oxidation reaction.

Pilot- and Large-Scale Applications

There are a great many variations on the type and arrangement of equipment and on the conditions of oxidation depending upon the effluent involved and the particular disposal requirements. In the pulp and paper industry the Zimmermann process has been applied to the treatment of spent pulping liquors for chemical or energy recovery and stream pollution abatement. The first commercial-scale trial of this process was made in 1954-1955 by the Hammermill Paper Company at Erie, Penn. for the disposal of pollution-causing organic material in spent sodium sulfite semichemical pulping liquor from their 30 ton/day Neutracel process [133-135]. A throughput of 50,000 gallons per day (gpd) of full strength spent liquor was oxidized in a series of three 3-ft x 30-ft reactors at 260°C under 800 psi pressure. Reactor products were separated and sent through heat exchangers to recover their heat. No steam or power production was attempted.

The average chemical and physical properties of the spent liquor before and after oxidation are shown in Table 44. Water loss due to evaporation during the process, some 60 percent of the original spent liquor volume, is reflected in the values of oxidized liquor properties contrasted on "as is" and spent liquor bases. Oxidation efficiency was 92 percent in terms of oxygen demand reduction or 88 percent in terms of heat content reduction. Residual biological oxygen demand (BOD) in the

TABLE 44

AVERAGE CHEMICAL AND PHYSICAL PROPERTIES OF SPENT NEUTRACEL[a] LIQUOR BEFORE AND AFTER OXIDATION [134]

Properties	Spent Neutracel Liquor	Oxidized Liquor	
		'As Is' Basis	Spent Liquor Basis[b]
pH	8.7	4.9	-
Specific gravity (at 80°F)	1.061	1.117	-
Oxygen demand[c]	91.5 g/ℓ	18.8 g/ℓ	7.5 g/ℓ
Total sodium	17.6 g/ℓ	43.8 g/ℓ	17.6 g/ℓ
Total sulfur	11.0 g/ℓ	26.3 g/ℓ	10.5 g/ℓ
Sulfate sulfur as S	-	22.1 g/ℓ	8.9 g/ℓ
Acetic acid	16.7 g/ℓ	25.3 g/ℓ	10.2 g/ℓ
Heat of combustion	6000 btu/gal	1800 btu/gal	720 btu/gal

[a] A sodium sulfite semichemical pulping process.

[b] Values corrected for water evaporated assuming no loss of sodium.

[c] Based on potassium iodate oxidation.

oxidized liquor, due almost entirely to sodium acetate, presented no pollution problem since the liquor was ultimately recycled into the Neutracel process. The inorganic pulping chemical, sodium, sulfite, present in the oxidized liquor as sodium sulfate, was recovered by treating the liquor with lime and sulfur dioxide; the basic reactions are shown below:

$$CaSO_3 + SO_2 + H_2O \rightarrow Ca(HSO_3)_2$$

$$Na_2SO_4 + Ca(HSO_3)_2 \rightarrow 2NaHSO_3 + CaSO_4$$

$$2NaHSO_3 + Ca(OH)_2 \rightarrow Na_2SO_3 + CaSO_3 + 2H_2O\ .$$

This regenerated the sodium sulfite pulping liquor, leaving calcium sulfate as a waste by-product. Preliminary results of the recovery process indicated that 80-90 percent of the sodium sulfate was converted to sodium sulfite; however, conversions in excess of 90 percent were thought possible.

Although the Hammermill Paper Company considered the wet oxidation process to be technically successful they did have some reservations related to large-scale sulfur and energy recovery. The Zimmermann process was not used for spent liquor treatment when the Neutracel process expanded into a new 100 tons/day mill in 1956. Cost data related to the construction and operation of the trial wet oxidation plant were never published.

Zimmermann and Diddams [136] later indicated that the wet oxidation process was successfully applied on a pilot-scale to magnesium-, calcium-, and ammonium-base spent liquor; to semichemical acid, neutral, and alkaline sodium sulfite spent liquor; to sodium-base liquor; and to kraft liquor. Inorganic chemical recovery systems for several of these liquors, including an alternate to the system used with the Neutracel process, were also developed.

In 1956 the Borregaard Paper Company decided to build a wet oxidation plant based on the Zimmermann process to recover the heat in the spent liquor from a 500 tons/day calcium-base sulfite pulp mill in Sarpsborg, Norway. Related studies [137-139] indicated that this process was 50-60 percent more efficient than the conventional evaporation-incineration method for the production of steam; and in addition, that a wet oxidation plant would cost $2.5 million whereas the cost for a comparable evaporation-incineration plant would be $3.8 million. Power requirements would be higher for the wet oxidation process. However, they could be met with the use of external sources or with energy recovered from the process.

In the installation [105], the spent liquor is first fermented to produce alcohol and then passed to the wet oxidation process at 105°C. Two 6-ft x 60-ft reactors operate in parallel at 310°-315°C under 2250 psig pressure. Reactor products move into a separator where the liquid phase is collected and discarded, and the steam and gases pass through reboilers for the production of 20-150 psig process steam and about 650 psig steam for a steam turbine. The noncondensable gases are passed through a gas turbine, and the power produced by the steam and gas turbines is used for air compression.

The wet oxidation plant has been in operation since early 1961, but the Borregaard Paper Company has not given out any performance or operation cost data to date. The process was to furnish 236,000 pounds per hour (pph) of process steam (6.2 tons of steam per ton of pulp), which represents a saving of about $1 million a year in fuel oil.

Additional applications have been evaluated and their implementation considered in several countries, such as Japan [140] and West Germany [141,142].

In the treatment of municipal wastes, wet oxidation has been utilized for the elimination of health hazards and nuisance conditions related to sewage sludge disposal, and for the economical reduction of the volume of this waste. The residue from such an application, almost without regard to extent of oxidation, is biologically stable, sterile, and can be compacted. These are characteristics which tend to simplify subsequent disposal [143]. Wet oxidation currently is being utilized for the disposal of one hundred to two hundred tons per day of municipal sewage solids in five cities in the United States.

The first application of the wet oxidation process to municipal wastes was in a pilot-scale study at the West-Southwest plant of the Metropolitan Sanitary District of Chicago, Ill. during parts of 1957 and 1958 [106,107,144-146]. The plant was designed to treat 2 tons/day (dry basis) of sewage sludge, and was operated with various combinations of primary and activated sludges at 260°C under 1200 psig pressure.

Average performance data for the pilot operation are shown in Table 45. These data indicate, as expected, that the extent of sludge degradation is a function of temperature and does not vary appreciably with changes in sludge concentration. Under the oxidation conditions employed, COD reduction was about 80 percent and volatile solids reduction approximately 89 percent. The process effluent, characterized in Table 46, was found to have a relatively high ammonia, volatile acid, and BOD content, and would require some treatment prior to disposal. The effluent, as discharged from the reactor, was sterile, and the settled ash biologically stable. An analysis of the gases exhausted from the process indicated they were mainly nitrogen and carbon dioxide, 82.8 percent and 13.9 percent (by volume), respectively. The hydrocarbon content was very low, less than 0.02 percent (by volume), and no air pollution problem was anticipated.

TABLE 45

AVERAGE PERFORMANCE OF PILOT-SCALE SEWAGE SLUDGE WET OXIDATION STUDIES [106, 145, 146]

Location	Volatile Solids Conc. Range %	Pres. psig	Temp. °C	Influent			Effluent			Reduction		
				Total Solids %	Volatile Solids %	COD g/ℓ	Total Solids %	Volatile Solids %	COD g/ℓ	Total Solids %	Volatile Solids %	COD %
West-Southwest Plant, Chicago, Ill.	2.00-2.99	1220	255	4.09	2.61	50.8	1.46	0.299	10.2	64.3	88.5	79.9
	3.00-3.99	1208	264	5.21	3.43	63.4	1.59	0.356	13.2	69.5	89.6	79.2
	4.00-4.99	1209	265	6.42	4.33	75.4	2.05	0.436	16.6	68.1	89.9	78.0
Salvo Chemical Co.[a], Rothschild, Wisc.	1.91-2.25	1525	274	3.29	2.16	44.5	1.14	0.24	9.3	65.4	88.6	79.3
	1.73-1.95	1820	277	3.48	2.31	49.8	0.92	0.17	8.1	73.6	92.4	85.1

[a] A subsidary of Sterling Drug, Inc.

TABLE 46

AVERAGE CHEMICAL CHARACTERISTICS OF PROCESS EFFLUENT FROM PILOT-SCALE SEWAGE LIQUOR SLUDGE WET OXIDATION STUDIES[a] [106, 145, 146]

Location	Volatile Solids Conc. Range %	Reactor Effluent						Settled Effluent		Effluent Ash			
		NH_3-N mg/ℓ	Org.-N mg/ℓ	Volatile Acids as Acetic mg/ℓ	pH	BOD mg/ℓ	COD mg/ℓ	BOD mg/ℓ	COD mg/ℓ	Volume Settled in 1 hr ml/ℓ	Volatile Content ml/ℓ	BOD mg/ℓ	COD mg/ℓ
West-Southwest Plant, Chicago, Ill.	2.00-2.99	1370	358	3200	--	5420	10200	4890	8300	98	--	530	1900
	3.00-3.99	1625	425	3480	--	7030	13200	6410	9800	105	--	620	3400
	4.00-4.99	1640	548	3980	--	8460	16600	7110	11600	116	--	1350	5000
Salvo Chemical Co.[b], Rothschild, Wisc.	1.91-2.25	1410	--	3930	6.1	--	9300	--	7800	--	108	--	1550
	1.73-1.95	1490	--	3820	6.3	--	8100	--	7030	--	--	--	967

[a] Oxidation conditions for the locations and volatile solids concentration ranges shown here are given in Table 45.

[b] A subsidary of Sterling Drug, Inc.

TABLE 47

SUMMARY OF TYPICAL OPERATING CONDITIONS FOR EXISTING SEWAGE SLUDGE WET OXIDATION PLANTS [107]

Plant Description			Typical Performance						
Location	Characteristics	Initial Operation Date	Sludge Characteristics	Solids Through-put, tpd	COD Reduction %	Insol. Organics Removal %	Pres. psig	Max. Temp. °C	Power Requirements
West-Southwest Plant, Chicago, Ill.	4 oxidn. units 1 - 12,500 kw power recovery air compressors (1/unit) 360 lb/min 2250 hp	December 1961	Raw primary-activated 3% solids 35% ash 40 g/ℓ COD	55/unit	75/unit	90	1750	275	Total: 2,000 kw/unit Net: 5,600 kw/unit (with 4 units on line) and power recov.
Wheeling, W. Va.	1 oxidn. unit air compressor 37.5 lb/min 225 hp	August 1961	Raw primary 7.5% solids 45% ash 70 g/ℓ COD	8	60	90	1140	260	Total: 200 kw
			Raw primary 4.4% solids 30% ash 52 g/ℓ COD	3	72	97	1650	275	Total: 160 kw
Wausau, Wisc.	1 oxidn. unit air compressor 23.4 lb/min 150 hp	October 1960	Primary digested 6.5% solids 56% ash 62 g/ℓ COD	5.7	75	92	1650	220	Total: 160 kw
South Milwaukee, Wisc.	1 oxidn. unit air compressor 5.0 lb/min 40 hp	October 1961	Primary raw and digested 7.7% solids 46% ash 60 g/ℓ COD	2.5	40	70	485	220	Total: 37.5 kw
Blind Brook Plant, Rye, N. Y.	1 oxidn. unit air compressor 7.0 lb/min 40 hp	April 1963	Raw primary 5.6% solids 30% ash 60 g/ℓ COD	1.4	65	90+	700	240	Total: 37.5 kw

In a subsequent pilot-scale study [106,146] by the Salvo Chemical Co., Rothschild, Wisc. (a subsidiary of Sterling Drug, Inc. which developed the Zimmermann process), higher rates of oxidation were attained at elevated temperatures and pressures without appreciable change in COD and volatile solids reduction. The plant had approximately half the capacity of the Chicago pilot operation and was run at 255°-285°C under pressures of 1500 or 1800 psig.

The reductions in COD and volatile solids at 1500 psig, shown in Table 45, were in the same range as those at 1200 psig; however, the sludge feed rate was higher. At 1800 psig these reductions, also shown in Table 45, were slightly larger and the feed rate was doubled. The process effluent from these operations, characterized in Table 46, was similar in ammonia and volatile acid content to that obtained at 1200 psig in the Chicago pilot study; the liquid effluent and ash COD contents were lower than those of the 1200 psig process.

As a result of these pilot studies the Metropolitan Sanitary District of Chicago, in 1959, contracted for the construction of four 50 tons/day (dry basis) wet oxidation units to treat some 20 percent of the sewage sludge from that area [106,107,146]. The plant was to provide ultimate disposal for sludge which was then being lagooned or sold as a low-grade fertilizer. Each unit consisted of a 7-ft x 62-ft reactor, six heat exchangers, four air compressors, and eight high-pressure pumps, and was designed to oxidize sludge of 3 percent concentration at 320°C under 1800 psig pressure. One turbogenerator was utilized for simultaneous power recovery from all four units. The plant was constructed at the West-Southwest Works of the Sanitary District and has been operating on a continuous basis since late 1961. Typical operating results are shown in Table 47.

The combined construction costs for this plant, itemized in Table 48, were almost $17 million, or $84 thousand per ton per day [141]. Operating costs for the first 16-18 months, also shown in Table 48, were $9.45 per ton (dry basis) of sludge treated; the combined capital and operating costs were $18.65 per ton (dry basis). A comparable, conventional disposal plant would have cost $25 million to build, and the resulting sludge treatment — digestion followed by disposal as fertilizer — about $35 per ton (dry basis).

Other wet oxidation plants have been built and are in operation in Wausau, Wisc.; Wheeling, W. Va.; South Milwaukee, Wisc.; and Rye, N. Y. A summary of the characteristics and typical operating results are also shown in Table 47. Actually the Wausau plant, put into operation in 1960, was the first commercial application of wet oxidation to sewage sludge disposal in the United States [147]. This plant was designed for almost complete oxidation of 3 tons/day (dry basis) of sludge, and was equipped with an expansion engine to recover mechanical energy from the process. No construction or operating cost data are available for this operation.

The Wheeling and South Milwaukee plants were started the following year and displayed a marked contrast in size and operating conditions. The Wheeling plant, designed to treat 5.6 tons/day (dry basis) of sewage sludge, attains about 90 percent removal of organic material at 260°C under 1200 psig pressure [148]. Under these conditions, the process operating costs, itemized in Table 49, are $19.97 per ton (dry basis). Installation costs for the wet oxidation unit were almost $300,000. The South Milwaukee plant, in contrast, was designed to oxidize 1 ton/day (dry basis) of sludge at 220°C under 525 psig pressure, and to reduce the amount of insoluble organic material by 70-80 percent [149]. No operating costs are available for this plant, but the wet oxidation unit, exclusive of buildings and other supplementary items, cost approximately $80,000.

The most recent wet oxidation plant, the Blind Brook plant at Rye, N. Y., was built in lieu of a digestion-filtration-incineration process at a savings in combined construction costs of over $400,000 [150]. This plant, designed to treat 1 ton/day (dry basis) of sludge, operates at 238°C under 750 psi pressure. Insoluble organic material reduction averaged 84.2 percent during the first year's operation. Estimated capital costs for two 1-ton/day units are almost $300,000 or $14.20 per ton (annual dry tonnage basis). Operating costs for such an operation, based on the

TABLE 48

UNIT COSTS FOR THE WEST-SOUTHWEST WET OXIDATION PLANT OF THE METROPOLITAN SANITARY DISTRICT OF CHICAGO, ILLINOIS[a] [141]

Item	Item Costs	Percent of Total Costs
Capital Costs		
Wet Oxidation Installation	$11,870,000	70.5
Maintenance Facility	808,000	4.8
Plant Foundation	398,000	2.4
Steel Framework, etc.	398,000	2.4
Electric Utilities	2,325,000	13.8
Sludge Concentration Installations	974,000	5.8
Miscellaneous Items	54,000	0.3
	$16,829,000	100.0
Operating Costs, per month		
Labor	$31,800	55.5
Lubricants and Chemicals	9,600	16.5
Replacement Parts	2,000	3.5
Steam	14,000	24.5
	$57,400	100.0
Operating Costs, per ton (dry basis)	$9.45	
Combined Capital and Operating Costs, per ton (dry basis)[b]	$18.65	

[a] Costs are based upon a continuous, 200 tpd (dry basis) sewage sludge disposal operation as of October 1963.

[b] No breakdown of capital costs on a per ton basis was given.

TABLE 49

UNIT COSTS FOR THE WET OXIDATION PLANT AT WHEELING, WEST VIRGINIA[a] [148]

Item	Item Costs
Capital Costs	
Wet Oxidation Installation	$284,000
Operating Costs, per ton (dry basis)	
Labor (1 man during operation)	$6.91
Electricity	6.11
Chemicals	4.13
Start-up Fuel	1.65
Maintenance	1.17
	$19.97

[a] Costs are based upon an intermittent 7.35 tpd (dry basis) sewage sludge disposal operation which operates 10 days per month, as of January 1965. No combined capital and operating costs per ton data were provided.

TABLE 50

UNIT COSTS FOR THE BLIND BROOK WET OXIDATION PLANT AT RYE, NEW YORK[a] [150]

Item	Item Costs
Capital Costs	
Allocated Capital for Wet Oxidation Installation	$263,000
Debt Service (30-yr bonds at 3%)	
Amortization per year	$ 8,800
Average Interest per year	4,000
Average Annual Capital Cost	$ 12,800
Annual Capital Cost, per ton (dry basis)	$ 14.20
Operating Costs, per day	
Power (1,480 kw)	$ 34.00
Chemicals	
Soda Ash	8.00
Caustic Soda	1.00
Water (2,250 cu ft)	9.00
Labor (6 hrs)	15.00
	$ 67.00
Operating Costs, per ton (dry basis)	$ 26.80
Combined Capital and Operating Costs, per ton (dry basis)	$ 41.00

[a] Costs are based upon a proposed 2.5 tpd (dry basis) sewage sludge disposal operation as of August 1965. The existing plant has a design capacity of 1 tpd (dry basis).

existing 1-ton/day unit and itemized in Table 50, would be $26.80 per ton (dry basis), and combined capital and operating costs $41.00 per ton (dry basis).

RECENT RESEARCH

As the preceding discussion indicates, in the past wet oxidation usually was applied to dilute aqueous dispersions of organic waste materials primarily with a particular disposal or recovery objective in mind. Under conditions of complete oxidation, this material (or materials) was degraded to inert gases and water, allowing recovery only of thermal and mechanical energy, and of inorganic chemicals. Under conditions of partial oxidation, it was converted to a more convenient form for physical disposal or utilization as fuel. The recovery of organic chemicals for their chemical value under either of the preceding conditions was largely neglected, and the question of their potential left unanswered.

The trend of research on wet oxidation now is toward the recovery of the organic chemicals for their chemical value as well as with the range of applications of the system. Of importance in this regard is the work of Grangaard [151,152] who investigated the production of organic acids – primarily acetic, formic, and oxalic – resulting from the degradation of ligneous waste materials, and from pulping wood with application of molecular oxygen under superatmospheric pressures and at elevated temperatures. Waste materials, such as spent pulping liquors or sawdust, are oxidized in aqueous alkali or buffer solution at 100°-225°C under 500-1000 psi oxygen pressure. Yields of different acids can be optimized under appropriate pH conditions, and combined yields can amount to about 80 percent of the material (dry basis) used. Simultaneous pulping and production of organic acids is carried out in a slightly alkaline, aqueous buffer solution under lower oxygen pressures and temperatures. The acids formed are similar to those in the preceding process, albeit in somewhat lower yields. Grangaard later noted [153] that such acids, produced from the spent liquor of a 100-ton/day sulfite pulp mill, had a potential annual market value of about $4.25 million, as shown in Table 51, which approaches the value of the pulp. In addition, applied to the 1960 production of sulfite and sulfate pulps in the United States, approximately 17.4 million tons, the potential production volume of these acids, also shown in Table 51, far exceeds the current domestic production.

Merriman _et al_. [154,155] at the University of California Forest Products Laboratory studied the formation of similar organic acids in the reaction of molecular oxygen with wood in aqueous acidic, neutral, or alkaline buffer solution at 150°-165°C under 100 psia oxygen pressure. Low molecular weight acids – mainly formic, acetic, oxalic, succinic, and glycolic – were formed as major products in all reactions; however, the yields of these acids varied significantly with pH. Under alkaline conditions total yield was highest – amounting to approximately 34 percent of the wood (dry basis) used. Under neutral and acidic conditions total yields reached about 12 percent and 9 percent, respectively. The cellulosic fraction of the wood was preferentially attacked under acidic conditions.

Recently, Brink _et al_. [156], using analytical techniques developed at this laboratory in the above study and in a related study by Bicho _et al_. [157,158], compared organic degradation products from alkaline nitrobenzene, molecular oxygen, and nitric acid oxidations of wood. These reactions were carried out in an aqueous medium under autogenic pressures or elevated oxygen pressure, and at temperatures ranging from 80° to 180°C. The oxidants involved are somewhat similar in oxidizing potential under the conditions employed. Low molecular weight organic acids were formed in all reactions, particularly in the nitrobenzene and molecular oxygen reactions under alkaline conditions. Aromatic acids and, to a lesser degree, aromatic aldehydes and ketones were also formed in these reactions. Total yields of these compounds ranged from approximately 10 percent of the wood (dry basis) used, for molecular oxygen and nitrobenzene reactions under alkaline conditions, to 4 percent for molecular oxygen and nitric acid reactions under acidic conditions.

APPLICATION TO SOLID WASTES

In the preceding discussion evidence in the form of examples and research results was presented, which demonstrates that the process of wet oxidation can be used effectively on organic materials, especially the highly carbonaceous forms, to recover potentially usable by-products and thermal energy. Moreover, the end product is in a form that is compact with no handling or disposal problems. In addition to demonstrations of technical feasibility, the process has been applied on a sufficiently large scale to simulate the economics of full-scale equipment and operation. Although heretofore the pilot- and full-production plants were constructed for specific applications, the type of equipment and processing would not change enough from one application to another to materially affect the overall costs.

TABLE 51

POTENTIAL VALUE AND VOLUME OF ORGANIC ACID PRODUCTION
FROM SPENT PULPING LIQUORS [146]

Acid	Annual Potential of 100 tpd Sulfite Pulp Mill		Annual Potential of Pulp Industry[a]	
	Production Volume lb/yr	Product Value dollars	Pulp Industry lb (millions)	Current Domestic Production lb (millions)
Acetic	3,840,000	384,000	668,000	764.7
Formic	9,240,000	1,501,500	1,610,000	14.0
Oxalic	9,648,000	1,736,640	1,680,000	21.3
Lactic	1,416,000	179,832	246,000	5.5
Malonic	648,000	-[b]	11,280	-
Fumaric	195,000	39,975	3,400	80.0
Maleic	216,000	80,460	3,760	90.1
Succinic	498,000	308,760	8,680	-
Itaconic	57,000	19,665	994	-
Citronic	-	-	-	-
Unknown	1,614,000	-[b]	-	-
	27,372,000	4,250,832	4,232,114	974.6

[a] Based upon 1960 production of sulfite and sulfate pulps in the Unites States, approximately 17.4 million tons.

[b] Value questionable.

Because of these two facts, viz., demonstrated evidence of the feasibility of the process and the availability of information regarding full-scale plants, an investigation of the potential of wet oxidation in the treatment of solid wastes is warranted. The extent of this potential is quite great inasmuch as organic materials constitute the greater part of the total volume of refuse. Admittedly, not all or even the major portion of the organics would be amenable to processing by wet oxidation. Nevertheless, the amount in the form of paper, which according to present evidence could be satisfactorily processed, is large enough to result in a substantial reduction in the size of the waste stream if it were so treated.

However, the extent of information concerning the process and the amount of experience with it is not great enough to permit its application to the treatment of solid wastes without a previous intensive investigation. In applications to date, wet oxidation has been applied to the disposal of organic waste materials under conditions of degradation approaching incineration at one extreme and biological oxidation or digestion at the other. As stated earlier, the recovery of organic chemicals for their chemical value under either of these conditions has been generally neglected, and the question of their potential has accordingly been left unanswered.

Nevertheless the overall promise of the wet oxidation process as currently utilized, and the potential of the process for the production of organic chemicals, particularly acids, as indicated by related studies, justifies the assumption that the process should be applicable to organic solid wastes.

OBJECTIVES OF STUDY

The overall objective of the studies on wet oxidation herein reported is to adapt the process to the conversion of organic solid wastes materials to products of commercial utility. Ultimately the research should lead to the making of correlations between material and energy balances and energy balances and reaction conditions which will lead to the development of the process designs needed for the realization of the general objective. Initial specific objectives, with which this report is concerned are to:

1. Provide an insight into the wet oxidation process itself.
2. Make possible a ready contrast of this wet chemical process with the more prevalent biological and chemical processes for solid wastes disposal.
3. Indicate the experimental approach to be taken in subsequent phases of the study.

Objectives 1 and 2 have been completed and reported in the preceding text. Objective 3 is discussed in the succeeding sections.

THE INVESTIGATION

During the period covered by this report investigative work was mainly preparatory in nature. An extensive literature review related to the development and application of wet oxidation was carried out and is summarily presented in the INTRODUCTION to this section. Pertinent questions raised by this review were considered in the formulation of the experimental plans which are described below. The plans are extensions of earlier work by D. L. Brink on the basic oxidation reaction and of more recent related studies at this laboratory. Although no experimental runs were made, work was done on the modification of analytical techniques for application in the study, especially of those related to the determination of aromatic compounds.

Program and Methodology

The experimental portion of this study has been divided into three phases which are to be approached sequentially. Work concerned with phases 1 and 2 will be done at least in part during the initial two years of the research program; phase 3, which is dependent on the results obtained in the preceding phases, will be undertaken during the proposed extended period of this program.

Phase 1: Determination of Basic Reaction Relationships.

Equipment: The initial stage of this phase, which is now in progress, is being devoted to modification of existing equipment and to the design and fabrication of additional equipment for the wet oxidation process. When the modification and installation have been completed, laboratory-scale reactions will be carried out in a 1.5 cu ft steam-jacketed reaction vessel which is augmented by an external circulation system consisting of a liquor pump, heat exchanger, and flowmeter, and by an auxiliary vessel for injection or collection of reaction liquors. This entire system will have a maximum design working pressure of 450 psig steam at 450°F (237°C), and all metallic surfaces of the equipment which will be in contact with the reaction have been and are being fabricated from type 316 stainless steel. Automatic, programmed temperature control will be provided by a cam-operated, pneumatic recorder-controller which operates a valve at the high-pressure steam inlet. The reaction system is and will be further augmented by an integrated instrumentation complex for monitoring and recording various reaction parameters such as pH, temperature, pressure, redox potential, and liquor flow rate.

The wet oxidation process employed in this phase of the study, and probably the next one as well, will be a batch operation, a schematic diagram of which is shown in Figure 30. A more detailed description of the reaction-instrumentation system is given in a paper presented at the 20th Alkaline Pulping Conference in 1966 [159]. In operation, a charge of a given waste material, dispersed in a minimal amount of water, will be added to the reaction vessel and rapidly brought to reaction temperature by applying steam to the jacket of the vessel and injecting additional preheated water into the reaction mixture. Air will be supplied to the reaction at a predetermined rate and pressure from a high-pressure storage-regulation system. Overall pressure in the reaction system will be maintained by a pneumatically controlled back-pressure valve. Mechanical agitation of the reaction mixture and dispersion of air in it will be accomplished with a dual-turbine agitator. Steam, volatile reaction products, and spent air will be expanded to atmospheric pressure and passed through an aqueous sodium bicarbonate scrubber to remove organic acids and condensable vapors. The remaining gases will be measured volumetrically with a wet test meter, analyzed periodically by gas-solid chromatography (GSC), and vented to the atmosphere. At the end of the reaction period, the reaction will be quenched by removing steam from the jacket of the vessel and injecting cold water into the reaction mixture. The residual waste material will be collected and subsequently analyzed by standard techniques.

To accomodate the proposed wet oxidation process, several modifications and additions have to be made to existing equipment. An 18-in. extension to the reaction vessel has been designed and is presently under construction to provide a disengagement zone above the reaction mixture and to allow top entrance for the agitator. A side entrance has also been provided in this extension and its application is discussed later. The agitator will be flange-mounted on this extension and has been designed to produce a downward flow of material in the reaction vessel. It will consist of two 5-in. diameter turbines, each having four blades pitched at a 45° angle, mounted on an 1-1/4 in. diameter shaft which passes through a balanced, double mechanical seal mounted on the face. Power will be transmitted to the agitator shaft from a 2-1/2 hp electric motor through a pulley-gear train assembly which is also mounted on the flange. Shaft speeds will be varied by changing the pulley ratio in this latter assembly.

Air required for the reaction will be provided by an integrated compressor-drier, storage, and pressure regulator system which has been designed for this

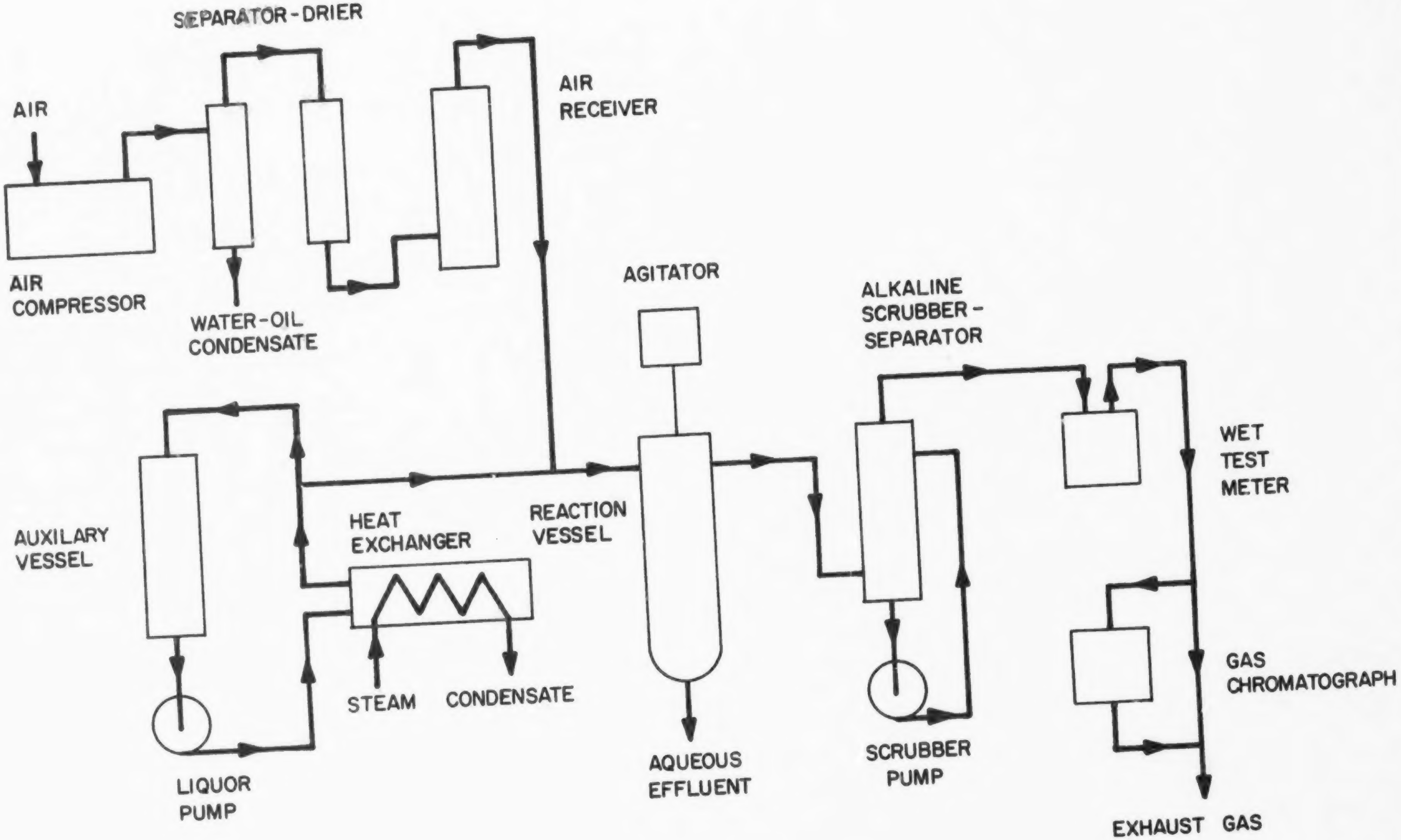
SEPARATOR - DRIER
AIR
AIR RECEIVER
AIR COMPRESSOR
WATER - OIL CONDENSATE
AGITATOR
ALKALINE SCRUBBER - SEPARATOR
WET TEST METER
AUXILARY VESSEL
HEAT EXCHANGER
REACTION VESSEL
GAS CHROMATOGRAPH
STEAM
CONDENSATE
LIQUOR PUMP
AQUEOUS EFFLUENT
SCRUBBER PUMP
EXHAUST GAS

FIGURE 30. SCHEMATIC DIAGRAM OF THE PROPOSED BATCH WET OXIDATION PROCESS

application and is shown diagrammatically in Figure 31. This system will also contain electro-pneumatic shutoff and fail-safe controls and mechanical pressure relief devices to avoid exceeding the design working pressure limits of the air and reaction systems. Air under standard conditions will be compressed to pressures up to 3000 psig at 4 cu ft per minute (cfm), physically separated from excess water and oil, chemically dried, and stored in two 3000 cu in. and one 1300 cu in. spherical receivers. These air receivers can be simultaneously or individually utilized through a manifold arrangement of pressure regulators.

The back pressure valve noted in the above discussion will be installed at an outlet on the reaction vessel extension, and will be controlled by an existing pressure indicator-recorder-controller in the instrumentation complex.

Procedure: Upon completion of the equipment modification, wet oxidation reactions will be carried out with wood chips or unbleached kraft pulp, or both, to establish basic reaction relationships and to correlate the results of these reactions with those from earlier studies at this laboratory. Reaction parameters to be considered will include: time, temperature, pressure, liquid-to-solids ratio, and agitation. Reaction time, i.e., time at temperature, will probably be limited to periods of four hours or less depending on temperature. Temperature, in turn, will be varied from 160° to 220°C at 20°C intervals. It is anticipated that at temperatures below 160°C the rates of reaction will not be practicable, and at those above 220°C the saturated steam pressure will preclude appreciable air input. Pressure will be considered in terms of total pressure and oxygen partial pressure. Overall reaction pressure will be maintained at an arbitrary 160 psig above saturated steam pressure in the reaction. Influent oxygen partial pressure under these conditions will be about 40 psig; average oxygen partial pressure in the reaction system, however, will be somewhat lower and will be controlled by the rates of air input and oxygen consumption. Solids content in the reaction mixture will be varied over a wide range to determine both practicable and technically utilizable values. Finally, agitation will be considered in terms of mechanical action and air dispersion. Agitator shaft speeds will be varied from about 250 to 1200 rpm in 200 rpm increments; the lower shaft velocity limit will be determined by the settling rate of the solids suspended in the reaction mixture. Turbine geometry will be changed from pitched to straight or curved blades, and possibly from a turbine itself to a hollow shaft-impeller assembly.

Reactions involving any of these parameters, individually or in combination, will be followed primarily by oxygen consumption and carbon dioxide-carbon monoxide formation as determined by pressure-volume relationships and GSC data. Additional supplementary analyses may be applied to the reaction mixture and volatile reaction products as required by experimental contingencies. Based upon the results of these reactions a standard reaction will be established and applied to various organic waste materials in phase 2. This standard reaction may not be optimum for the production of organic chemicals; however, it will serve as a reference for comparison of these materials.

Phase 2: Oxidation of Organic Solid Waste Materials. In this phase will be applied the experimental techniques and results developed and obtained in phase 1 to the treatment of additional organic waste materials such as paper, agricultural residues, sewage sludge, food processing residues, and combination of these and other materials. The organic chemical production potential of these materials will be determined. No immediate, additional equipment requirements are anticipated for this application. Material balances will be established by standard analytical techniques. Chromatographic-spectrophotometric techniques developed in earlier studies or in response to the needs of this study will be used to characterize the organic reaction products.

Further reactions under conditions specific for the production of a given organic chemical or group of chemicals will be carried out in the later stages of this phase. This application may require a pressurized inlet system, which would be mounted on the side entrance of the reaction vessel extension, to allow periodic

SPECIFICATIONS

Design working pressure,
3000 psig:

Compressor rating,
4 cfm at 3000 psig:

Storage capacity,
7300 cu. in. (absolute)
or 860 cu ft of air at
S. T. P.

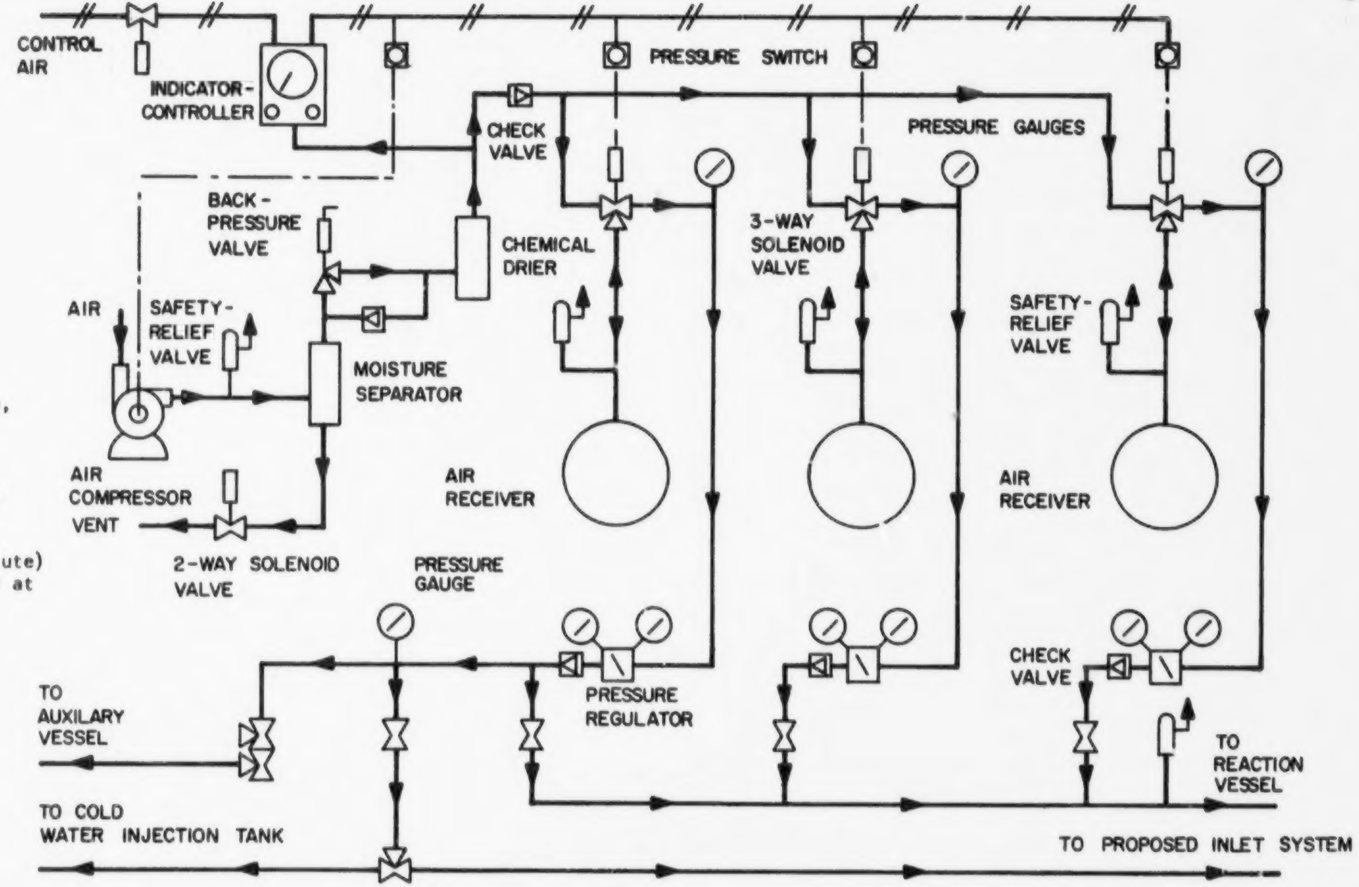
CONTROL AIR
INDICATOR-CONTROLLER
PRESSURE SWITCH
CHECK VALVE
PRESSURE GAUGES
BACK-PRESSURE VALVE
CHEMICAL DRIER
3-WAY SOLENOID VALVE
AIR
SAFETY-RELIEF VALVE
SAFETY-RELIEF VALVE
MOISTURE SEPARATOR
AIR COMPRESSOR
AIR RECEIVER
AIR RECEIVER
VENT
2-WAY SOLENOID VALVE
PRESSURE GAUGE
CHECK VALVE
TO AUXILARY VESSEL
PRESSURE REGULATOR
TO REACTION VESSEL
TO COLD WATER INJECTION TANK
TO PROPOSED INLET SYSTEM

FIGURE 31. SCHEMATIC DIAGRAM OF AIR SYSTEM DESIGNED FOR WET OXIDATION PROCESS

introduction of waste material into the reaction vessel during the reaction. Organic chemical production potentials and material and energy balances determined at this stage will provide the basis for process design development in phase 3. Additional experimental work related to a particular process will be performed in that phase.

Phase 3: Process Design. In this phase the results of the preceding phases will be assimilated in the development of possible process designs for the production, isolation, and utilization of organic chemicals from wet oxidation of solid waste materials. Processes involving production and isolation of these chemicals probably will be considered as one process or as a series of integrated processes. Utilization processes, such as acid hydrolysis of specific carbohydrate waste materials, will be dependent upon the results of the above processes, and will be developed in the later stages of this phase. Extensive equipment requirements related to the individual processes are anticipated for this development phase. Economic analyses of each process design or combination of designs will be provided to indicate expected costs or cost-profit ratios.

Progress in Eqipment Modification. Most of the equipment modifications discussed earlier are beyond the design stage and are in varying stages of construction. Fabrication of the reaction vessel extension is well under way and should be completed by the middle of June. Work on the agitator assembly is progressing as various components are received and the assembly should be operational in late summer 1967. Lastly, the high-pressure air supply system, which is the most extensive of all the modification activities, is also near completion. The various subassemblies, electrical controls, and air transfer lines will shortly be joined together into an integrated system. With the possible exception of a few back-ordered components this system should be completed in the latter part of July. Upon completion of the various modifications the overall reaction system will be subjected to a number of trial reactions and then applied to the experimental aspects of phase 1.

DISCUSSION

The approach taken in this research, namely of producing organic chemicals from waste materials, implies several considerations which have not as yet been discussed. Usually, the wet oxidation process is applied to dilute aqueous dispersions of organic wastes which neither technically nor economically would be practicable to treat by other means. Taking a reclamation rather than a disposal viewpoint toward such applications may remove many of the restraints currently applied to the process. In a reclamation or utilization approach all organic wastes, regardless of form or condition, are considered to be technically suited to the process and the use of them would be economically justified in terms of chemical production.

The wet oxidation process involves hydrolysis and pyrolysis as well as oxidation. As such, this process initially degrades waste materials to simpler organic compounds and then to carbon dioxide and water. This intermediate level of degradation is of primary concern in this study because it dictates both the quality and quantity of organic chemical production, and the design of the process. The utilization of waste materials in a complementary manner would allow control of the organic content and concentration of the reaction mixture. Such control coupled with appropriate reaction conditions provides the basis for chemical production. This would be of particular significance in the case of an abundant organic waste material such as paper, which comprises some 40 percent to 65 percent of the total solid wastes, and which could be converted to organic acids by this process.

Additional considerations are the much lower temperature and pressure requirements of a utilization-oriented process as contrasted to those for a disposal process. These modified reaction conditions would have a marked effect on equipment design criteria, and all other factors notwithstanding, would lower subsequent construction costs.

More immediately, in terms of these considerations, existing pulping equipment and related instrumentation at this laboratory can be adapted to the experimental requirements of this study. Most of the requisite modifications to the equipment have been designed and, to a large degree, fabricated.

FUTURE WORK

As indicated earlier, the study will progress from a planning-experimental stage to an active experimental stage within the next few months. Most of the experimental requirements for phase 1 and most of phase 2 have been met (or soon will be), although some additional requirements are anticipated. Further modifications may be dictated by experimental contingencies. For example, the proposed GSC technique for analysis of reaction gases may not be applicable to experiments involving short reaction times. Such experiments would require modification of this technique or application of fast-scan mass spectrometry, or both. A similar situation would prevail for any equipment component which did not perform as expected.

The conversion of the reaction system from batch to continuous operation in the later stages of phase 2 will require the design and fabrication of additional equipment. This will include the pressured inlet system discussed previously and a high-pressure pump for intermittent removal of aqueous reaction products. Additional insulation of the overall system may be needed to insure accurate heat loss-gain data for energy balance calculations. A small high-pressure reaction vessel may also be required to supplement experimental results noted under lower temperature-pressure conditions. Extensive equipment requirements related to various process designs are anticipated in phase 3. Specific needs are difficult to predict in this instance because of their reliance on the results of the preceding phases.

IX. BIOLOGICAL FRACTIONATION OF ORGANIC WASTES

INTRODUCTION

Biological fractionation of the organic content of solid wastes is another possible process of indirect recycling of materials from the wastes stream to the basic resources of the nation. It differs in concept from anaerobic digestion in that by-products of elevated economic value are produced, whereas digestion is intended to reduce volume and yield a residue which may be disposed of to the land with mimimum insult to that resource. Biological fractionation also produces a usable solid residue. In regard both to intermediate products and to usable residue it parallels wet oxidation, the difference being that in one case the oxidation or fractionation is biochemical, in the other it is physiochemical.

The general rationale underlying the experimental work on biological fractionation is the same as that described in the preceding section on wet oxidation. Similarly, the research plan calls for initial experiments with the paper fraction of solid wastes, extending to other mixed organic wastes if the work with paper produces satisfactory results. Reasons for considering the process worth investigating are to be found both in a general knowledge of the role of celluloytic microbes in the decomposition of dead plant material in nature, and in the fact that a large number of microorganisms have been demonstrated as being cellulose degraders. For example, Siu [160] and Gascoigne [161] list several hundred of such species. However, the organisms vary widely with respect to cellulolytic activity, necessary environmental conditions, types of metabolic products, etc. The problem is to find those most efficient and amenable to economical engineered systems.

WASTE TREATMENT ORGANISMS

A survey of the literature has shown a number of groups of the organisms to be especially promising for waste treatment applications. Among them are the cattle and sheep rumen microorganisms, cellulolytic clostridia species, and some of the fungi imperfecti.

Rumen Bacteria

The mixed microbial population of the rumen consists of bacteria and protozoa. The protozoa probably have only a minor role in the decomposition of cellulose. Rumen microorganisms are strict anaerobes. In vitro studies consistently give relatively rapid decompostion rates. Halliwell [162] reports the decompostion of nearly 90 percent of a cellulosic powder substrate within 48 hours in a batch culture in which by-products were not removed. Stranks [163] observed a decompostion of 83 percent of the cellulose in a filter paper substrate within 72 hr. In his experiment, end products were removed by ion exchange and dialysis. Stranks noted also that the decomposition rates were much lower in experiments in which no provision was made for removal of the end products. Rumen microorganisms are more difficult to culture successfully because of their fairly specific environmental requirements. Until rather recently, rumen liquor had to be used as a part of the substrate. However, Quinn [164] has shown that it is possible to grow rumen microorganisms in continuous culture on a chemically defined medium.

Clostridia and Related Forms

Several varieties of thermophilic cellulose decomposing bacteria have been isolated from the soil with the use of cellulose as the sole carbon source.

Extensive work has been done by Enebo [165] in the isolation of such organisms, on the determination of their fermentation rates and their metabolic products. In his working with *C. thermocellulosium* he observed that fermentation rates were higher in cultures having other bacteria in addition to *C. thermocellulosium* than in pure cultures of the organism. According to Enebo, the slower rate in the pure culture was due to the accumulation of reducing sugars such as glucose. In a mixed culture glucose is used by other microorganisms as rapidly as it is produced.

In Table 52 (from Enebo [165]) is shown the distribution of fermentation products by a pure culture of *C. thermocellulosium* and by a mixed culture containing *C. thermocellulosium*, *C. thermobutyricum*, and *B. thermolacticus*.

TABLE 52

DISTRIBUTION OF FERMENTATION PRODUCTS
BY PURE AND BY MIXED CULTURES [165]

Item	Pure Culture[a]	Mixed Culture[b]
Incubation time (days)	10	6
Portion of cellulose fermented (%)	40.1	100
Acid production (g/g of cellulose)		
Ethanol	0.160	0.150
Formic acid	0.054	0.017
Acetic acid	0.191	0.290
Butyric acid	0.0	0.300
Lactic acid	0.431	0.048
Reducing substances (as glucose)	0.117	--

[a] *Clostridium thermocellulosium*.

[b] *C. thermocellulosium*, *C. thermobutyricum*, and *B. thermolacticus*.

The thermophilic cellulose decomposers seem to degrade cellulose fairly rapidly, although not quite as rapidly as do the rumen microorganisms. Because the former only function at elevated temperatures (55°-65°C), systems in which they are used are penalized economically because of the cost of maintaining the higher temperature. However, a compensation rests in the fact that the higher temperatures reduce the chances of contamination by unwanted bacteria, since the number of thermophiles is small.

Fungi Imperfecti

Because of its cellulose decomposing capacity, *Mycothecium verrucaria* QM 460 probably would be one of the more effective of the members of the fungi imperfecti in the treatment of solid wastes. Among the earlier workers who recognized its superior cellulose decomposing potential were Siu [160] and Reese and Levinson [166]. Using loss in tensile strength of cotton duck as a measure, Reese and Levinson found that of all the fungi tested, *M. verrucaria* was the most active. They observed that the loss was 100 percent when *M. verrucaria* was used. Although a great deal of work has been done on the investigation of the cellulose decomposing capacity of *Mycothecium*, most of it was done with the use of cell-free preparations of cellulase which had been synthesized by the organism. In an investigation on the action of a cell-free enzyme extract from the fungus, Saunders et al. [167] found that 16 percent of the cellulose in a preparation of ground filter paper was decomposed within 5 days (temperature at 40°C).

APPLICATION TO SOLID WASTES

Reports in the literature amply prove that groups of bacteria exist in nature which can rapidly decompose cellulose under conditions that have been defined and hence can be incorporated into practical processes, among which could be one for waste treatment. Such a process would yield only a minimum amount of offensive gases (which could be easily controlled), and the amount of solid residue from the cellulosic fractions would be quite small. The strong possibility exists that useful products can be obtained with the process in operation and that these could prove important in offsetting the cost of the treatment operations. Enough is known about the metabolic processes of the cellulose decomposers to enable the predicting of metabolic products under given conditions. These products include certain substances such as glucose and organic acids (e.g., butyric, succinic, propionic, acetic, and formic).

Any biological process that centers on the decomposition of cellulose to usable and/or stable end products is especially valuable in modern waste treatment, since as was shown in this section, cellulose constitutes such a large fraction of the total output of refuse. The stabilization and recovery can be done in a manner that meets two important criteria for good waste treatment: 1) the wastes undergoing treatment do not reappear in other forms of waste (air, water, or terrestrial pollution);and, 2) useful substances are being produced, i.e., the converted wastes are recycled as resources.

The fact that microbial decomposition of cellulose is a natural ecological process, lends a good prospect of success to any technique involving the use of microbes to recycle the carbon in wastes. A major part of the problem of waste disposal stems from the fact that man interferes with ecological equilibrium by generating more wastes than can be decomposed by natural means. Since man has and is interfering with the equilibrium of nature, it seems logical that a powerful means of combating the waste problem would be to attempt to restore the equilibrium. Therefore, in the long run, a process to decompose cellulose microbially would be highly feasible, since it would restore normal ecological succession instead of creating an imbalance of another type, i.e., produce an environmental pollutant.

Although much information is available about the identity and the activities of cellulose decomposers, many questions remain unanswered; and in addition, little or nothing is known about the systematic use of the organisms in waste treatment. In terms of the cellulolytic activities of the microorganisms, most of the work done thus far has been with the use of cell-free enzyme extracts and with soluble forms of cellulose such as carboxymethyl cellulose. While helpful, information gained in such studies is not sufficiently extensive for use in setting up a waste treatment process. High cellulolytic activity on soluble derivatives is not in general a reliable indication of a microbe's ability to attack nonsoluble cellulose. Therefore, in the present study only those microorganisms which have shown a relatively high rate of decomposing nonsoluble cellulose have been chosen for study.

In addition to the need for additional fundamental information on the biology of the cellulolytic microorganisms, ways must be found for applying this information, once it has been gained, and other available information to the design of a practical and economically feasible treatment system in which useful products can be recovered.

OBJECTIVES OF STUDY

The general or long-term objective of this phase of the overall research on waste management is the development of a pilot plant in which microorganisms can be utilized continuously to decompose the cellulosic fraction of solid wastes. To attain this objective it will be necessary to: 1) determine the feasibility of the recovery and utilization of decomposition products; and 2) develop methods with which product recovery can be made an integral part of the process in order that the fermentation products can be recycled into the economy as resources.

The immediate and specific aims of the research are:

1. Determination of the optimum range of key environmental factors.
2. Identification and determination of the quantity and rate of production of decomposition products.
3. Evaluation of the effect of the heterogeneity of the nature of refuse and of the microbial population in the refuse.
4. Determination of the potential utilization of the fermentation products.

THE INVESTIGATION

The investigation has thus far consisted in surveying the literature on cellulose decomposers; in making a preliminary run to arrive at culture handling procedures; and finally, in developing a methodology for carrying out the principal investigation.

In the initial phases of the investigation a preliminary study was made of the isolation and maintenance of cultures of cellulose decomposers. Cultures were started as enrichments from soil. The initial enrichments demonstrated a fairly high degree of cellulolytic activity. However, the activity seemed to decline after several transfers. The cultures also seemed to be adversely affected by agitation. The reasons for both of these inhibitory effects will be sought in future research.

Experimental work planned for the investigation in the immediate future is concerned with selecting microorganisms and determining the type of culture to be used. Only those microbes capable of decomposing nonsoluble cellulose will be used in the study. At the start, those groups considered in the literature as being very active cellulose decomposers will be used, viz., rumen bacteria, C. thermocellulosium and related species, and M. verrularia. As the investigation progresses, screening studies will be made to select those organisms best suited to meet the conditions expected to be encountered in waste treatment. Two criteria will be applied in making a selection, viz., rate of attack on cellulose and the economic value of the fermentation products.

Pure and mixed cultures will be used. If a defined culture should prove necessary, techniques and costs of the sterilization of the paper fraction of solid wastes will be made. When mixed cultures are used, certain naturally occurring or artificially constituted mixtures will be used. Use of mixed cultures has a potentially valuable aspect. If the noncellulolytic species present in the culture are able to utilize the cellulose hydrolysis products (mainly glucose and cellubiose), they may in fact enhance the rate of cellulose decomposition by preventing a buildup of these products, which would otherwise inhibit the action of the cellulolytic microbes.

Assuming that no difference exists between the fermentation rates of mixed and of pure cultures, several advantages and disadvantages can be ascribed to each mode of operation. If a pure culture is used, the feed would have to be sterilized to assure maintenance of a pure culture. The cost of sterilization would have to be considered in determining the economic feasibility of the system. If a mixed culture is used sterilization would not be necessary but using a mixed culture opens the possibility of the symbiants becoming the predominant organisms if any impurity in the cellulose waste could be used as a carbon source by these organisms. Should this occur, cellulose fermentation might cease completely.

The batch type of culture will be used in the initial stages of the research. This type will be used in determining the optimum ranges of the environmental conditions, in identifying decomposition products and ascertaining their quantities and rates of production, in evaluating the effects of the heterogeneity of the refuse and of the competition of other microorganisms present in the refuse on the rate of decomposition, and finally in determining the extent of the potential utilization of the fermentation products. Environmental factors to be studied are nutrition, cell density, aeration rate (for aerobes), temperature, and pH.

The batch cultures will be followed by small-scale continuous cultures, each grown in a chemostat-type apparatus. Factors investigated in the "batch-type" runs will be again studied in the experiments with the continuous cultures. Additional experimentation with the continuous cultivation will be concerned with the new variables of nutrient and cellulose feed rates as well as with methods and rates of product removal.

An important aspect of the experiments with continuous cultures will be the continuous removal of end products from the culture. A method of removal which appears promising is the combination of dialysis and ion-exchange techniques suggested by Stranks [163]. In Stranks' apparatus a dialyzing sac is suspended in the fermenter and an ion-exchange resin (Amberlite IRA-400) was placed inside the sac to take up the end products of fermentation as they passed through the dialysis membrane. An alternate method of removal would involve the use of a molecular sieve.

The greater part of the product analyses will be carried out with the use of a gas chromatograph (Aerograph 1520). The rate of cellulose decomposition will be measured by successive gravimetric determinations of the residual cellulose in the medium. The determination will be carried by means of a technique developed by Reese [168]. The principal problem involved in making gravimetric determinations is the minimizing of the amount of cell material filtered together with the cellulose. The structural characteristics of the mycelium aggravates this problem when fungi are the microorganisms being studied. Treatment with alkali serves to reduce the error somewhat, but it does not entirely eliminate it.

When the most promising organisms have been selected and the environmental and other conditions have been evaluated and determined, the information thus gained will be used in the design and construction of a pilot plant for the continuous fermentation of cellulose. The design of the plant will include provisions for pH and temperature control, as well as the continuous removal of decomposition products.

SUMMARY

After the literature was reviewed two groups of strictly anaerobic bacteria and a member of the fungi imperfecti were selected as the most promising of the microorganisms with respect to cellulose decomposition under the conditions to be met in the treatment of solid wastes.

In preliminary experiments it was found that, though very active in their cellulolytic activity when first isolated, cellulose exhibited a tendency to diminish this activity upon being subjected to repeated subculturing. Agitating the cultures was found to exert an inhibiting effect on the growth of organisms.

The following program of research activity involves the conduct of the research in three successive steps:

1. With the use of batch cultures
    - (a) determine the optimum levels for the various key environmental factors;
    - (b) evaluate the effects, adverse or otherwise, of the peculiar nature of refuse and the presence of other organisms on the activities of the cellulose decomposers;
    - (c) develop methods for removing the end products.
2. With the use of continuous cultures, again seek information on the items listed for the batch culture and in addition, determine the effect of nutrient and cellulose feed rates and methods and rates of product removal.
3. Using information gained in steps 1 and 2, design, construct, and operate a pilot-scale plant for the continuous fermentation of cellulose.

PART IV

X. SUMMARY

INTRODUCTION

Progress is reported for the first year of a program of research entitled "Comprehensive Studies of Solid Wastes Management." A consideration of such factors as the structure of modern communities; the impingement of the urban, suburban, industrial, and agricultural sectors of the community; the fragmentation of jurisdictions concerned with solid wastes problems; the social and aesthetic goals of man; attitudes of citizens and public officials in relation to economics, resource conservation, etc.; and the realities of technology and the indestructibility of wastes lead to the fundamental precept that solid wastes must be managed on a community-wide basis. Thus it is made evident that such disciplines as planning, engineering, public administration, law, demography, political science, public health, geography, economics, and sociology must develop a common understanding and work in harmony in solving the problem of solid wastes management. To this end the research program involves both studies of management techniques and the education of individuals from the several participating disciplines through research participation in a co-ordinated program.

The problem of solid wastes management is defined both in terms of magnitude and scope of concern. In relation to the former it is shown that the wastes produced by man's use of resources has grown from some 2 lb/person/day to the order of 6 to 8 lb/person/day. Part of this growth results from increasing opulence of Americans and a spendthrift attitude. Part of it is from the growth of his scope of concern from that of municipal refuse to include as well such fractions as agricultural residues, animal manures, demolition debris, food processing residues, sewage sludge, industrial wastes, and old automobiles and junk. It is pointed out that a large fraction, perhaps 50 percent, of this total must inevitably be consigned either to the land or to the ocean, unless acceptable ways are found to recycle such residues to the basic resources of the nation.

A chart is presented to show that there are but seven possible types of waste disposal systems for dealing with all or with selected fractions of the overall solid wastes. These are:

1. Reduction at source — e.g., reducing the amount of material discarded as wastes.
2. Diversion at source — e.g., discharging to water or piling on land by the waste producer.
3. Disposal to land or ocean sink — e.g., sanitary land fill, ocean dumping, or undersea filling.
4. Change of state — e.g., incineration.
5. Direct recycling to resource — e.g., salvage.
6. Indirect recycling to resource — e.g., pyrolization, chemical or biological oxidation, rendering, reprocessing, animal feeding.
7. Conversion — e.g., composting, digestion.

NATURE OF RESEARCH PROGRAM

To approach the problems of solid wastes management a research program was developed having the following major objectives.

1. To bring the competence of people in the wide variety of disciplines involved in planning, financing, and administering a community into effective combination with that of engineers and environmental health specialists in seeking solutions to problems in solid wastes management which are technically sound, economically feasible, and politically and socially acceptable.

2. To bring the techniques of modern operations research to bear upon the organizational problems of managing solid wastes on an area-wide or community-wide basis; and on the physical and logistic problems of collecting, transporting, and disposing of wastes.

3. To seek through experiments and other research techniques improvements in conventional methods of wastes disposal and the development of new procedures for reclaiming or recycling fractions of the refuse mass.

4. To identify and seek answers to problems involving man's health and well being that may be associated with solid wastes and related to his use of land, water, and air resources.

5. To develop, through participation in research, greater understanding and knowledge on the part of engineers, planners, administrators, economists, public health specialists, and others who are confronted with the problem of solid wastes management in the course of their professional service to the modern urban-industrial-agricultural community.

6. To insure, through close coordination and effective communication with public and private agencies, the pertinence of research to real problems and the prompt availability of the results of research to professional practitioners.

Pursuant to these objectives and under a grant from the U. S. Public Health Service a research group was organized. It consisted of University faculty members and graduate students, assisted by professional specialists, from the departments of City Planning, Operations Research, Sanitary Engineering, Public Health, Mechanical Engineering, Forestry, Chemical Engineering, Agricultural Engineering, Economics, and Civil Engineering. All faculty participants in this group, together with the project coordinator, formed a coordinating board which met biweekly with all participants in the program to give direction and coordination to the program activities.

The research plan that followed and herein reported included two phases. The first, in which all participants functioned as a single investigative unit, albeit with assigned individual tasks, involved Data Collection and Evaluation. The specific activities of the group during Phase I included the following:

1. Collection and evaluation of published information on the technology and management of solid wastes.

2. Establishment of an information retrieval system.

3. Interviews and discussions with officials and operating personnel of public and private agencies concerned with solid wastes management in the San Francisco Bay and Los Angeles areas.

4. Collection and evaluation of data on the composition and amount of the various fractions which in combination constitute the overall solid wastes of a community.

5. Definition and coordination of discrete areas of research to be undertaken in Phase II by the individual research teams.

Following completion of certain aspects of Phase I, and as rapidly as proved feasible, the research group was broken into a number of research teams for Phase II of the program. This phase involved Definitive Research in four major areas of closely coordinated research and made use of nine research teams.

1. Operations Research

2. Planning and Economics

3. Public Health

4. Technology

    (a) Incineration

    (b) Composting

    (c) Landfill (Public Health team)

    (d) Salvage

    (e) Anaerobic Digestion

    (f) Wet Oxidation

    (g) Biological Fractionation

RESEARCH ACTIVITIES AND FINDINGS

Phase I

In this aspect of the research more than 500 documents were assembled and abstracted and incorporated in a manual (notched card) retrieval system. A general evaluation of those documents is reported.

Orientation and informing of the research group was furthered by interviews and discussions with public and private individuals responsible for managing solid wastes in the San Francisco Bay and Los Angeles County areas of California. Twelve refuse disposal sites covering all degrees of landfill practice were visited and studied.

Specific studies of the composition and amounts of solid wastes generated in a modern community were made. Cooperative arrangements were made with the California State Department of Public Health to furnish detailed data from its statewide and Fresno city studies under PHS demonstration grants; and from the Food Machinery Corporation which is collecting data on industrial wastes in Santa Clara County, Calif. under a similar grant.

The investigative team itself obtained data from a literature search, personal interviews, case histories, and field studies in Santa Clara County and the City of Berkeley. From these, a general estimate of the quantity and composition of areawide refuse was made and reported (Chapter II). Specific estimates were also made and reported on the basis of field studies and general information in Santa Clara County. In this case estimates, tabulated in the report, were made for domestic wastes, industrial wastes, agricultural wastes, and animal manures.

In the field study at Berkeley, municipal wastes were segregated and the various components weighed for comparison with a similar study made at the same site in 1952. From these data important conclusions are reported relative to the change in refuse composition with time. (See Chapter II.)

The final aspect of Phase I was the production of a Regional Waste Generation and Evaluation Model (see Figure 9, page 39, Chapter II) involving a series of submodels to which work of the various research teams could be directed during Phase II in a coordinated manner and with a common goal.

Phase II

The research plan envisioned that within the first year of study Phase I would be completed and Phase II advanced to the point that definitive research subprojects were well defined and evaluated both for pertinence to the overall solid waste problem and for the prospect of positive results. The work proceeded according to plan and achievements exceeded the general expectation of the investigators. As might be expected, the data collection and evaluation aspects of Phase I are a continuing aspect of research. Likewise not all aspects of Phase II were initiated at the same time nor advanced at the same rate. Specifically, such areas as operations research and planning were involved in definitive research almost from the beginning of Phase I, others of the nine research teams began work at various appropriate stages of the study. All established well defined approaches to definitive research representing necessary and coordinated aspects of the overall waste generation model developed in Phase I. The report presents the nature and results of each definitive research area during the report period (first year).

Operations Research

The operations research team developed a mathematical model based on the conceptual model of Phase I and considered the ways in which its subsystems could be applied in optimizing solid wastes management decisions and operating procedures. The work proceeded from the general concept that the broad interdisciplinary problem of effective management and operation of refuse handling systems is of the type which is within the traditional domain of operations research. Details of the mathematical model by which to predict the wastes generated by a community and to optimize the collection, treatment, and disposal activities are presented in the body of the report. Examples of application of such an evaluation model are included in an appendix.

Planning and Economics

Definitive research by the planning and economics team proceeded from the general rationale that since some fraction of solid wastes must inevitably remain on the land, land-use planning for a community must include some provision for that fact. Conversely, those responsible for the technical and economic aspects of wastes management must take into consideration the cultural realities of the times. Working closely with the operations research team the planning team therefore directed attention to those aspects of wastes generation which relate land use to the nature and volume of refuse materials to be managed. The way in which wastes generated by a community derives from how many people use how much land for what purposes was given major attention. Using Santa Clara County as a laboratory in which to study wastes generation, rather than as a case in point, four major factors were explored:

1. Location of disposal sites and definition of service areas.
2. Land use and employment.
3. Solid wastes generation.
4. Composition of solid wastes.

A series of tables were developed which give an insight into waste generation. Some of the data were then used for developing regression models to study waste generation as a function of economic activity of a community. These models explain the variation in solid wastes generated in relation to such variables as population, land use, employment, etc. Of particular importance was the early identification of the extent of detailed information which must come from the cooperating agencies or from field studies by the research team itself in order that the land-use model generate the inputs needed for the overall evaluation model which is to produce an optimal plan of decisions and operations for management of solid wastes. Work toward generating such inputs is progressing in accord with a sequence of objectives described in the body of the report.

Public Health

In considering the public health aspects of solid wastes management it was first concluded that public health concern should transcend the epidemiology of disease in relation to wastes and include also such matters as nuisance and other environmental constraints by which solid wastes may make human life less pleasant, convenient, or healthy. While experimental studies might not be directed to all such sociological phases, meaningful inputs to the overall evaluation model call for attention to several objectives of study. These include:

1. Evaluating the true relationship between solid wastes management procedures and health dangers to the public.

2. Reviewing critically all public health regulations relating to solid wastes management with particular reference to the source and validity of any numerical values imposed.

3. Advising all other research teams of the known or possible health implications of their alternate proposals for wastes management.

4. Considering the components of solid wastes and the environmental fate of each in wastes disposal, with particular reference to the health and welfare of humans.

5. Conducting definitive research on such of the components of solid wastes which are judged likely to have a significant effect on human health or welfare.

6. Evaluating the occupational hazards to workers in the solid wastes management field.

Work of the public health research team took two major directions:

1. A consideration of the health implications of the various individual materials occurring in refuse of all types within a community, with particular reference to the fate of such materials during each method of disposal.

2. The conduct of experimental studies of those materials found to be released into the environment of humans by refuse management procedures which might be judged to have a significant potential hazard to human health.

Results presented in the report concern largely the first of these two lines of investigation. The incineration, composting, and landfilling with domestic, agricultural, industrial, and mixed wastes were analyzed with respect to their pollutional effects on air, land, and water environments. Such materials as lead, asbestos, beryllium, and cadmium were reviewed in relation to the human contact that might result from solid wastes management. In the future the public health research team's attention will be directed to experimental studies, but it will continue to serve as an advisory group to all other research teams proposing new technologies.

Technology

Studies of the technology of solid wastes management proceeded along three main lines of approach:

1. Improvement of existing technology — incineration, composting, landfill, and salvage.

2. Adaptation of existing processes to a wider spectrum of wastes — anaerobic digestion with sewage sludge.

3. Application of known processes to the development of new technology — wet oxidation, biological fractionation.

Progress is reported in relation to each of the several main lines noted.

Incineration — The study of incineration as a refuse disposal project was based on the rationale that the furnace should be managed as a device for producing useful power or steam rather than as a device for disposal of wastes. Under this concept, solid wastes represent a fuel to be burned at such times and at such rates as the product of the furnace demands, rather than as a converter into which wastes are dumped at varying rates during an eight-hour refuse collection day. However, to operate a furnace in such a manner, fuel must be amenable to storage in an acceptable condition and of relatively constant quality and uniformity. The incineration research team has, therefore, directed attention to preliminary studies of refuse pretreatment problems such as segregation, particle-size reduction, and drying, and to economical ways of resolving them. The study of these items led to a consideration of pyrolysis as a means of pretreatment. Accordingly, a study of pyrolysis also was made. This latter process might be expected to produce liquid and gaseous fractions as well as a solid combustible residue. All are usable as fuels under existing technology and are capable of being stored. The possibility also exists that some of the fractions, such as for example acetic acid, methanol, and mixed solvents, might be more valuable as resource materials than as fuel, and so enhance the economics of the process as well as its conservation merits. Conceptual and pilot-plant design studies pursuant to the concepts cited are being pursued.

Composting — No experimental work on composting was initiated during the period herein reported. Nevertheless, it was given attention at the Phase I level. First, literature references on the subject were compiled and incorporated in the project's retrieval system. The fate of various materials in refuse, particularly biological agents of disease, was evaluated by the public health team on the basis of reported observations. Most important to the future of the project when it entered Phase II was the study of composting plants and the use of compost in agriculture in Germany. This investigation was conducted by one of the faculty investigators of the project on sabbatical leave from the University. From this study it is evident that the careful scientific studies of pathogen inactivation made in Germany are applicable to U. S. conditions and that a safe compost can be produced even with the inclusion of sewage sludge in the raw material. Agricultural use abroad, however, is motivated by economic and other factors not characteristic of U. S. agriculture. Consequently, Phase II of the composting research, scheduled to begin in the 1967-68 period, is to be based on the general rationale that a time lag between production and use of compost must be envisioned. Furthermore, it must be determined whether the process itself might be justified on the basis of reduction and stabilization of organic matter prior to landfilling, with a resultant decrease in land area requirements and in "insult" to the land resource. Finally, it is noted that composting has been associated with the municipal refuse fraction of solid wastes, or with individual special fractions, rather than with the entire spectrum or organic wastes of a community. Phase II will therefore be directed to an exploration of:

1. The feasibility of assembling organic fractions of the overall solid wastes of a community which might complement each other in the composting process.
2. The minimum parameters of a composting process suited to:
    - (a) Preparing refuse for landfill with a minimum volume and "insult" to the land.
    - (b) Producing compost from mixed organic wastes at a minimum cost.

Landfill — Due to the extensive previous work on landfilling conducted by the project investigators, and the wealth of practical experience with the method in the U. S., no definitive research on this aspect of refuse management was undertaken during the period reported. Phase I activities were concerned with the economic, public health, and sociological problems of landfilling by the planning and public health teams. The model developed by the operations research team requires consideration of the land use, transportation, and economic aspects of landfill. No productive results are expected to derive from specific attempts to improve the technology of landfill, except possibly undersea filling. Definitive research on this aspect is considered for a future phase of the investigation.

Salvage — Definitive research on salvage was developed around the concept that the ideal solution to the solid wastes management problem is one which results in the maximum reduction in the generation of wastes by way of reuse and recycling of residues. The reuse by industry of its own residues, which never appear in the wastes stream that the community must manage, are not in fact a part of the management problem. Much of the 5 to 7 billion dollar activity of the "Salvage" industry is therefore outside the area of immediate concern. For purposes of study, salvage is therefore related to the extracting of materials from the wastes stream for return to the basic resources of the nation either with or without intermediate processing.

During the period herein reported a search for information was directed to:

1. The literature.
2. Scientists whose background gives them an expertise with respect to certain components of the wastes.
3. Processors and salvors who deal directly with the components.

Specific studies were made of such fractions of solid wastes as metals, paper, glass, rubber, plastics, and rags, and principal findings are reported in relation to source, marketing, use, economics, etc. From the information presented in the body of the report it is evident that the salvage material from mixed municipal refuse is a declining practice. Moreover, simple economics is an inadequate basis for salvage as a method of solid wastes management. Objectives of resource conservation, reduction in landfill areas, air pollution control and similar public goals of refuse management must some day motivate the practice of salvage.

Anaerobic Digestion — The well established anaerobic digestion of solids, including household garbage, separated from municipal sewage might well be applied to a broader spectrum of the organic wastes of a community. An exploration of this possibility through laboratory and pilot experiments was the objective of a definitive research team beginning in November 1966. While the end product of this process is still a solid waste, it is greatly reduced in volume and, like compost, might be applied to agricultural land or placed in landfills with limited insult to the land resource. Other factors favorable to the process are that treatment plants are already located at acceptable places in the community; the process is one of the best known methods of treating organic wastes; and an underground transporation system exists which might be made to deliver shredded organic solid wastes during off hours.

Initial experiments were directed to the amount of garbage in relation to sewage sludge the system might handle. Successful digestion with garbage at 3 times the amount of sewage sludge is reported with only a 14 percent reduction in gas production per pound of volatiles destroyed and a 7 percent reduction in methane production. When acclimating of digesters preceded maximum loading, digesters fed at 4:1 and 5:1 garbage-to-sludge ratios performed satisfactorily.

Forthcoming experiments will involve the addition of such other fractions of solid wastes as paper, animal manures, grass clippings, and tree trimmings.

Wet Oxidation and Biological Fractionation — Two separate research teams began investigative work on the fractionation of organic wastes by chemical and biological means. In contrast with anaerobic digestion, the objective of the two studies is to produce chemical byproducts of a liquid or gaseous nature which are valuable as raw industrial chemicals, plus a residue which might also be utilized in such applications as the production of gypsum board, packing, etc.

The wet oxidation is a modification of the Zimmermann process but involving concentrated dispersions of solid organic wastes and temperature and pressure in the 200°C and 400 psia range, far below those used in the Zimmermann process. Initial experiments with wood residues have indicated that the process is feasible. The pilot plant used in the initial experiments was rebuilt during the period reported herein. During the coming period, experiments will be initiated in which waste paper will be the raw material. Successful application of the process to waste paper would in itself be a major contribution to the technology of solid wastes management. However, if it does prove feasible with paper, then grass clippings, sludges, tree trimmings, animal manures, and garbage will be incorporated in the material to be processed and the experiments repeated.

In a similar manner biological fractionation experiments are planned for paper and, subsequently, for mixed organic refuse. The research team concerned with this facet of the investigation completed a literature survey and has designed experiments for the second year of study. In these experiments such bacteria as the rumen bacteria, the Closteridia and mixed cultures of cellulose fermenters, as well as certain forms of the fungi imperfecti, will be studied in relation to their ability on a practical basis to produce amino acids or other valuable fractions from organic wastes.

GENERAL SUMMARY OF PROGRESS

During the first year of research the project completed Phase I (Data Collection and Evaluation) of its objectives and began Phase II (Definitive Research) in accord with plans. Nine research teams in the four major areas of planning, operations research, public health, and technology refined their objectives, coordinated their efforts, and engaged in definitive research on systems essential to the success of an Overall Wastes Generation and Evaluation Model. By 1 June 1967 (end of first year) all had made progress — some producing experimental data, others in various stages of design of experiments, the details of which are described in the body of this report.

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APPENDIX A

APPLICATION OF THE EVALUATION MODEL TO SPECIAL CASES

To illustrate the broad application of the regional model, three examples of optimization studies of management systems are simply outlined [39].

Expanded Existing System (Transfer Station)

This is a specialization of the general regional model where the final disposal sites are fixed and it is desired to test the feasibility of adding transfer stations to aid in the collection operation.

Development System (Treatment Plant)

Here the final disposal site-location is fixed and the possibility of using solid-to-liquid treatment plants to reduce overall collection costs is considered. If this conversion plant is stationary the familiar location-allocation problem is similar to the Expanded Existing System. An alternative idea is to have mobile treatment plants. These would take the form of a mobile grinding truck capable of towing a special pickup lift truck. The operator would set up over a centrally located solid waste pickup point where the solid waste would be fluidized and dumped into the sewer system. There seems to be many interesting problems here. Possibly our regional model could be used if plants located at each pickup point are considered. Obviously, in this case the need is to investigate secondary problems similar to the traveling salesman to ascertain equivalent stationary plant costs.

Advanced System (Disposal Site)

In this future system it is assumed that technology has advanced to the extent that there exists some sort of automatic household collection device which operates as follows. The homeowner deposits solid waste into a wall inlet which is collected in a container beneath or beside the home. An underground conveyor belt transports the waste out to and under the street and deposits it on a central underground belt running beneath the center of the street. A street conveyor transports the waste to the nearest predetermined intersection or collection point and dumps it into an underground container. This underground container would be emptied periodically by rubbish collection devices such as road or rail vehicles integrated with the rapid transit system. Most of the solid refuse would be transported to automated gaseous-, liquid-, and solid-processing and separating plants where little residue remains after processing. The problem would be to find the optimal location-allocation and size of the final disposal sites given the collection or pickup points. This is just another specialization of the model.

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APPENDIX B

DESIGN OF TRANSFER STATION CHARACTERISTICS

Introduction

Initially a single-period static model of transfer plant operation is examined. The refuse input profile may be taken as either stationary throughout the period (year) or vary seasonally. A one-period cost function is defined over a decision vector representing the transfer station operational characteristics for a fixed location. This function is to be minimized over a vector of design variables subject to city planning and budget constraints. The optimal expansion of the transfer station over time, is then considered as a stochastic multiperiod sequential decision problem reflecting refuse growth and economic predictions.

Single-Period Static Model

General Description: In this section the operation of a transfer station is formulated where its location-allocation and associated operational costs for a single period are given. The classifications and various combinations of transfer station components are extremely numerous. The following three main components, however, seem to persist throughout all transfer station configurations.

(i) Waste collection trucks which comprise the input or arrival stream considered to emanate from an infinite reservoir.

(ii) Haul trucks which form a second arrival stream from a finite reservoir (the fleet of haul trucks).

(iii) Transfer channels of various types, quantities, and service characteristics.

The characteristics suggest the formulation of a transfer station as a queuing system. Before embarking on a detailed description of this formulation we make the distinction between two types of transfer stations--direct and indirect.

Direct Transfer Station: The basic attribute of a direct transfer station is the operation of transferring refuse from one or more collection trucks directly into a haul truck. (Assume capacity of a haul truck $\geq$ capacity of a collection truck.) As shown in Figure 32 when the disposal operation is considered along with the transfer station operation we obtain a cyclic queuing situation with a fixed number of hauling trucks which possibly develop queues in front of each of two types of service channels. A waiting line of collection trucks may also evolve in front of the collection-haul truck type of channel.

Indirect Transfer Station: An indirect transfer station is a facility at which two types of transfer operations are performed on a "parcel" of refuse before it is carried to the disposal area by a hauling truck. The first type of transfer, designated as a collection-storage type, occurs between the incoming collection truck and the refuse storage lot. Parcels of refuse are then transferred from the storage lot to a hauling truck in a second type of operation. Again when the disposal operation is considered we obtain a cyclic queuing situation, but with an additional service channel placed in series with the incoming stream of refuse (cf. Figure 33). An important quantity in this system is the queue length (or inventory) at the storage lot and possibly its waiting time.

State Space: Define the expanded state space of an indirect transfer station as the three-dimensional space of vectors n representing the numbers of items at each of the three service channels.

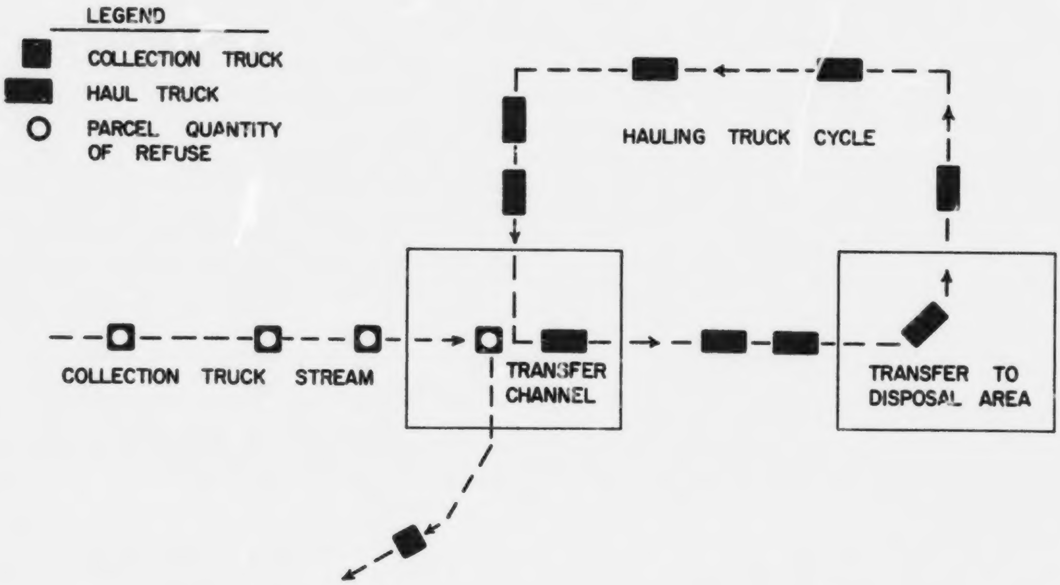
LEGEND
COLLECTION TRUCK
HAUL TRUCK
PARCEL QUANTITY OF REFUSE
HAULING TRUCK CYCLE
COLLECTION TRUCK STREAM
TRANSFER CHANNEL
TRANSFER TO DISPOSAL AREA

FIGURE 32. DIRECT TRANSFER STATION AND DISPOSAL STATION

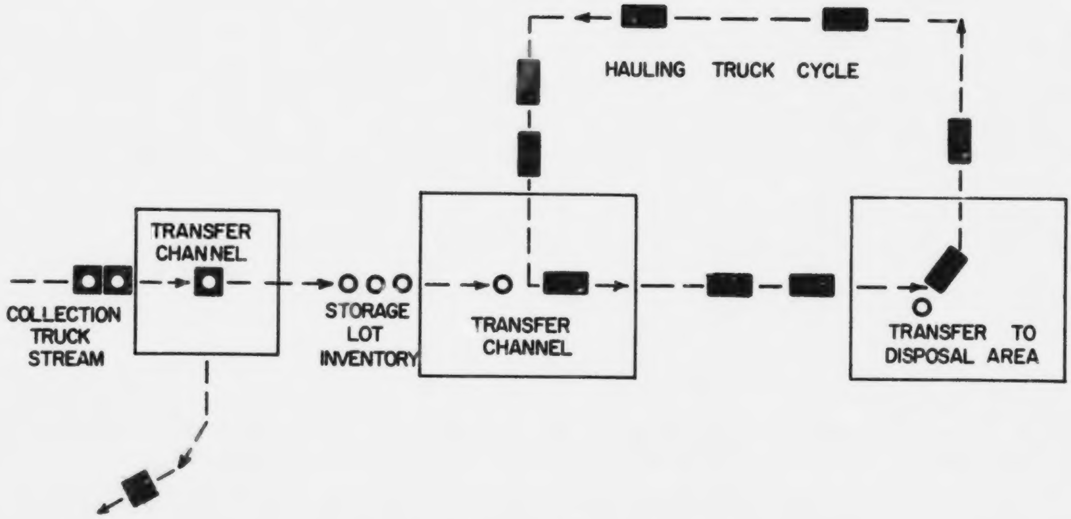
HAULING TRUCK CYCLE
TRANSFER CHANNEL
COLLECTION TRUCK STREAM
STORAGE LOT INVENTORY
TRANSFER CHANNEL
TRANSFER TO DISPOSAL AREA

FIGURE 33. INDIRECT TRANSFER STATION AND DISPOSAL STATION

Let $n = (n_c, n_h, n_s)$

where: n_c = the number of collection trucks present at the collection-storage channel; n_h = the number of haul trucks present at the storage-haul channel; and n_s = the quantity or number of parcels of refuse in the refuse storage lot or being loaded into haul trucks.

If K_h is assumed to represent the number of haul trucks in the fleet, then $K_h - n_h$ indicates the number of haul trucks in the final disposal system. We may also define queue limits of K_c, K_h, K_s as the maximum number of units in the respective channel subsystems indicated by the subscripts. These values reflect the limitations on transfer facility capacity in terms of storage area, parking lot size, and hauling truck fleet; thus they represent important design characteristics.

For the direct transfer station we reduce the vector n to a two-dimensional vector by setting n_s and K_s to zero and redefining n_c as the number of collection trucks present at a collection-haul type channel. A further delineation is required to adequately describe the state space. It is assumed that the random variables representing the elements of the random state vector only take on non-negative integer values divisable by some common factor ("parcel"). This, of course, implies an expansion of the number of elements in the domain of n as the degree of refinement is increased.

Number and Types of Transfer Channels: The number of transfer channels of a particular type represents the maximum possible number of simultaneous refuse operations of that type. The following types of transfer channels are defined.

(i) Collection-Haul Channel (ch) -- A service facility in which the operation of transferring refuse from a collection truck(s) directly to a haul truck takes place.

(ii) Collection-Storage Channel (cs) -- A transfer channel in which refuse is removed from a collection truck to the storage lot.

(iii) Storage-Haul Channel (sh) -- A transfer channel in which refuse from the storage lot is loaded into a haul truck.

(iv) Haul-Disposal Channel (hd) -- The channel in which refuse from the haul truck is unloaded into the final disposal area.

Let M_{ab} represent the number of channels of type (ab). The upper bound on the number of transfer channels of a particular type should be consistent with the systems capacity limits, i.e.,

$$M_{ch} \leqq \min \left[K_c, K_h \right]$$

$$M_{cs} \leqq K_c$$

$$M_{sh} \leqq K_h$$

$$M_{hd} \leqq K_h$$

The range of variation of the M_{ab}'s from between zero and their respective upper bounds, represents the design domain for these operational characteristics.

Arrival Characteristics: Most likely in a realistic situation the inter-arrival time distributions of collection trucks will be non-stationary, i.e., will reflect seasonal variations. One possible approximation is to let the distribution of arrivals be non-homogeneous Poisson distribution allowing the arrival rate $\lambda_c(t)$ to vary over time according to the time of day or year. Additionally, one may consider the quantity of refuse carried by the i^{th} collection truck to be independent random variables with a common distribution defined over some finite probability space.

Thus, a compound Poisson distribution may be used to represent the total amount of refuse arriving at the transfer station over some time interval. The accuracy of this assumption, however, should be tested empirically.

Service Characteristics: The term service characteristics denotes the service time distributions for the respective channels and queue disciplines.

(i) Queue Discipline: Assume a "first in first out" queue discipline for all types of channels, although in some cases the storage-haul truck transfer channel may have a "last in first out" discipline. Since trucks may be carrying different loads, and therefore may have different service times, initially a simplifying assumption is made. This assumption is that the queue discipline takes no account of the difference between different truck load classes so that we may now take the service times to be pooled distributions by using the appropriate proportions.

(ii) Zero Service Time: If the time of transfer of refuse from the collection truck(s) to the haul trucks may be considered negligible the problem for a direct transfer station is extremely simplified. The state space at this channel may then be reduced to a single dimension where either haul trucks or collection trucks are queuing, but not both. (This is accomplished by defining the state space as having positive as well as negative integers.) In the indirect transfer station case the collection trucks never queue while the refuse level and haul trucks may form non-simultaneous queues. The disposal area channels for both direct and indirect cases will represent total haul truck round trip time if the unloading service time is considered negligible.

(iii) Service Time As A Non Negative Random Variable: A simplifying assumption until further data is received is to let all channels except the haul-disposal have exponential service time distributions. The total service time of a haul truck is equal to its round trip time plus some unloading time at the disposal area. This service time would most likely be some finite time with a random error term superimposed on it. This type of service could be represented by an equivalent infinite channel system with common general distribution (to allow passing of haul trucks).

System Interruptions: For continuous (24 hours per day) operation it may be appropriate to use steady state results to represent the systems operational characteristics for the period (one year) providing "convergence" is reached in a relatively short time compared to the diration of the period.

For conventional intermittent (8 hours on and 16 hours off per day) operation, a steady state condition may never be reached. One must then examine the transient behavior of the system in order to ascertain equivalent long term state operational characteristics. Of particular importance here is the expected number of collection trucks turned away, during the "on time" of the system, due to queue limits.

For the direct transfer station, the probability distribution of the number of collection trucks in the system at the time of shutdown is of interest; these correspond to unserviced customers. Of equal importance is the number of hauling trucks not at the channel at the time of shutdown, and the total expected time until all return representing overtime costs. The initial conditions at the start of each on time interval are considered to be identical for each cycle. That is, the system is assumed to start each new cycle with zero, (or some finite probability distribution) collection trucks queuing at the collection-haul channels. The total fleet of K_h haul trucks will also be waiting at these channel entrances.

The situation is not so simple in the case of the indirect transfer station. In addition to the operational features described for the direct transfer station we are concerned with the initial and terminal "on period" (8 hr) inventory level in the storage area. The terminal waste storage level will depend on the terminal situation of the previous day. This markov property allows one to obtain a steady state solution (assuming one exists) for the storage lot level once the single-step transition probabilities are determined.

Optimization of Single-Period Transfer Station Design

Let the one-period (annual) cost function of a transfer station in terms of its design factors given arrival, service, and cost parameters be denoted by C(D,V,P). The design vector D of a transfer station specifies various channel quantities, and queue-limit capacities, and is represented as:

$$D = (M_{ch}, M_{cs}, M_{sh}, K_c, K_s, K_h).$$

Assume that M_{hd}, the number of disposal area channels, is given. Also, for a direct transfer station K_s, M_{cs}, and M_{sh} are all set to zero. V is the vector of depreciation, operating, and penalty cost coefficients for the period (one year). We may define V as being composed of six cost elements, i.e.,

$$V = (V_1, V_2, V_3, V_4, V_5)$$

where

V_1 = the annual depreciation cost coefficient of the transfer station facility including the hauling truck fleet. This set of cost coefficients is some function of the design vector D and the actual location of the transfer station.

V_2 = Annual operating cost coefficient. This cost is a function of the design vector D and the level of activity in say dollars per ton of refuse transferred.[a]

V_3 = Penalty cost coefficient of unit overflow of collection trucks. This cost is the difference between collection trucks serviced through a transfer channel and direct routing to the disposal area.

V_4 = Penalty cost coefficient of collection trucks not serviced at the end of the operating phase (for intermittent operation only).

V_5 = Overtime operational penalty cost coefficient for haul trucks (for intermittent operation only).

The vector P represents the set of elements defining the arrival and service patterns (based on a given location-allocation).

The objective is to minimize the cost function over $\bar{D}$, the set of admissible designs D. This set may be determined by budget limitations, present available land at the given location, and/or other city planning constraints. The optimal one-period operational design characteristics of the transfer station is designated as D* and is obtained when the cost function is minimized. Thus

$$\min_{D \in \bar{D}} C(D,V,P) = C(D^*,V,P)$$

This minimization problem is most likely nonlinear and involves integer variables, and additional research will be needed to develop solution techniques.

---

[a] This cost may be based on intermittent operation or continuous operation.

Optimal Expansion Plan of a Transfer Station over N Periods (Dynamic Model)

One immediately recognizes that the optimal transfer station design for the static model need not remain optimal once the predicted growth of solid waste generation and its impact on collection truck activity is considered. Consequently, one should examine the optimal design criteria over the future use of the station. The decision variables now become the design characteristics of the transfer station at each period. For an N-period model the sequence of decision vectors $(D_1^*, D_2^* \ldots D_n^*)$ denotes the optimal N-period expansion plan for the transfer station given the refuse and cost profiles over the horizon. It may be possible to use dynamic programming to find the optimal expansion plan if the dimension of D is small.

Conclusion

As may be seen from the general formulation of a transfer station, an abundance of interesting queuing situations are suggested. Unfortunately, not all of these situations are amenable to direct analysis, and it is presumed that for those situations that are not, either gross approximations must be made or simulation attempted. There are configurations, however, that do seem attractive for operations research investigations. These investigations appear in such areas as semi-markov chains, nonlinear mathematical programming, dynamic programming, and queuing theory. Moreover, analogous studies and research may be conducted for the optimal design of waste treatment plants.

APPENDIX C

COMPARABLE DATA ON SOLID WASTE AND RELATED ECONOMIC VARIABLES

Definition of Disposal Service Area		Demographic & Economic Characteristics		Employment				Land Use				
Sites Incl.	Geographic Area Served (Census Tracts)	Pop. & No. of Households	Income	Agri-culture	Manufacturing		Comm. & Services	Resid.	Agri-culture	Manufacturing		Comm. & Services
					Food	Non-Food				Food	Non-Food	
Site A												
Site B												
.												
.												
Total Disposal Service Area (1)												
Site E												
Site F												
.												
.												
Total Disposal Service Area (2)												
Total County (or city) (Group of Disposal Service Areas)												
Total Region (Group of Counties)												
Total State (Sum of Regions)--Calif												

COMPARABLE DATA ON SOLID WASTE AND RELATED ECONOMIC VARIABLES (Continued)

Solid Wastes												Costs		
By Source					By Material					Properties of Waste		Coll. & Transp.	Disposal Cost	Supervision & Management (Public Exp.)
Resid.	Agri-culture	Manufacturing		Comm. & Services	Garbage Paper	Metals	Plastic	Bottles	Others	Heat Content	C/N Ratio			
		Food	Non-Food											

APPENDIX D

Solid Wastes Management Project

Economics, Planning, and Operations Research Phase:

A Questionnaire To Refuse Collectors and Disposal Site Operators for Analysis of Refuse Collection and Disposal

Center for Planning and Development Research
University of California, Berkeley

Name & Address of Refuse Collector:

____

DATA FOR ANALYSIS OF URBAN REFUSE COLLECTION AND DISPOSAL

I. Equipment Used:

Description	Capacity Tons or cu yd	Number of Units	Annual Maintenance & Depreciation Cost	Cost of Fuel	Average Fuel Miles/Gal.	Type of Fuel	Size of Crew	Trips/Day to Dump	Average hrs/day In Use	Average days/week In Use

II. Collection Routes:

Area Covered	Type of Route	Avg. lb/week Collected	Distance			Trips Required to Cover Route	Total Time Required to Cover Route	Type of Equipment Used
			Garage-Route	Route-Dump	Dump-Garage			

County ______________________

III. Disposal Site Operations:

(1) Name of the site: ____

Owner: ____

Operator: ____

(2) Land area and cost of site:
Total land area __________ acres; Cost of purchase: $ __________

Starting date of operation: ______________________________

(3) Acres of land filled to date: __________; Acres remaining __________

Avg. depth of fill __________ ft. Acre-feet remaining __________

(4) What is the service area from which solid refuse is brought to the disposal site: Mark it on the county map.

(5) Approximate estimate of refuse filled in the site during the past year (1965)

tons/week ________________; tons/year ________________

cu yds/week ________________; acre ft/year ________________

(6) Breakdown of refuse by type:

Category:	Percent of total:
Residential garbage ________	
rubbish ________	
Commercial (food wastes)	
Commercial (paper and allied)	
Industrial (manufacturing)	
Cannery and food processing	
Agricultural (farming) wastes	
Special wastes: (Specify)	
____________________	
Municipal waste: (Sewage Treatment Sludge)	
Total:	100.0

(7) Disposal operation:

Number of (full-time equivalent) men employed at the site	
Number & type of equipment used	
Average lift height	
Cover material source ( )	(thickness)
( )	
Total depth fill & cover	
Average density of fill	(lb/cu yd)

(8) Cost of disposal operation: (Obtain detail data and enter total cost or per unit cost)

Labor________________________

Machinery_____________________

Material______________________

(9) Source of revenue to meet the cost of operation: (Obtain detailed data as available)

Direct user charge ______________________

Tax revenue ______________________

APPENDIX E

CODIFICATION OF DATA

Identification of Observations:

Each observation may be identified by:

A. County (58 such counties)
B. Disposal service area (10-15 per county)
C. Some subcounty unit such as
    census tract
    county census division (group of census tracts)
    city (group of census tracts)

It will be necessary to aggregate the observations in any of the following manners:

Sum of appropriate subcounty units = Disposal Service Area

Sum of Disposal Service Areas = County

Sum of counties = Region

or Sum of counties = State of California

For these purposes, the following code is suggested:

A. Two-digit county code
B. Two-digit disposal service area code
C. Three-digit subcounty area code:
    1-499: correspondingly numbered census tract
    501-599: county census division within county
    901-999: city within the county

The following examples are offered to illustrate the use of the identification scheme:

0206043: Census tract #43, D.S.A. #06, County #02.

1304501: County census division #501 (some census tracts grouped) for D.S.A. #04, County #13.

1304901: City #1, D.S.A. #04, County #13.

0607000: The sum of all observations for D.S.A. #07 in County #06.

Major Data Blocks:

The following major categories of data are required:

A. Demographic characteristics (no totals required)
B. Employment (totals required)
C. Land use (totals required)
D. Solid waste (totals required)

The detailed data requirements within each of these blocks are presented below at various levels of aggregation.

A. Demographic characteristics:

1. Population
2. Number of households
3. Average household size (population/number of households)
4. Total personal income
5. Average household income (total personal income/no. of households)
6. Per capita income (total personal income/population)

	Corresponding SIC Code
B. Employment, total	
1. Agricultural employment, total	
a. field crops	
b. orchard crops	
c. dairy	
d. livestock	
e. other agricultural employment	
2. Mining and extractive employment, total	13-14
3. Manufacturing employment, total	
a. food and kindred products employment, subtotal	20
(1) meat products	201
(2) dairy products	202
(3) canned and frozen foods	203
(4) grain and bakery products	204-205
(5) other food processing employment	
b. non-food manufacturing employment, subtotal	
(1) tobacco products	21
(2) textile mill products	22
(3) apparel and related products	23
(4) lumber and wood products	24
(5) furniture and fixtures	25
(6) paper and allied products	26
(7) publishing and printing	27
(8) chemical and allied products	28
(9) petroleum and coal products	29
(10) rubber and plastic products	30
(11) leather and leather products	31
(12) stone, clay, and glass products	32
(13) primary metal products	33
(14) fabricated metal products	34
(15) machinery, non-electrical	35
(16) electrical machinery	36
(17) transportation equipment	37
(18) instruments and related products	38
(19) ordnance	19
(20) misc. manufacturing employment	39

4. Commercial and service industry employment, total

a.	construction	15-17
b.	transportation, communication and utilities	41-49
c.	wholesale trade	501-509
d.	retail trade	52-59
e.	finance, insurance, and real estate	60-67
f.	personal and business services	70-89
g.	government	90-99

C. Land, total acres

0. Residential use, total acres

   a. single family
   b. multiple family
   c. special and group residences

1. Agricultural use, total acres

   a. field crops
   b. orchard crops
   c. dairy
   d. livestock
   e. other (including grazing and range land)

2. Extractive industry use, total acres

3. Manufacturing use, total acres

   a. food and kindred products, subtotal acres

      (1) meat products
      (2) dairy products
      (3) canned and frozen goods
      (4) grain and bakery products
      (5) other food processing use

   b. non-food manufacturing, subtotal acres

      (1) tobacco products
      (2) textile mill products
      (3) apparel and related products
      (4) lumber and wood products
      (5) furniture and fixtures
      (6) paper and allied products
      (7) publishing and printing
      (8) chemicals and allied products
      (9) petroleum and coal products
      (10) rubber and plastic products
      (11) leather and leather products
      (12) stone, clay, and glass products
      (13) primary metal products
      (14) fabricated metal products
      (15) machinery, non-electrical
      (16) electrical machinery
      (17) transportation equipment
      (18) instruments and related products
      (19) ordnance
      (20) misc. manufacturing land use

4. Commercial and service, total acres
    a. transportation, communication and utilities, total acres net of street and roads
    b. wholesale trade
    c. retail trade
    d. finance, insurance and real estate
    e. personal and business services
    f. government (facilities)

5. Other uses, total acres
    a. public open space
    b. other public (military reservations, etc.)
    c. urban vacant
    d. rural vacant
    e. other misc. uses

D. Quantity of solid waste (data to be collected by the California State Public Health Department)

1. Quantity of solid waste by source, total
    a. households
    b. agricultural industry
    c. extractive industry
    d. manufacturing industry, total
        (1) food processing industry
        (2) non-food manufacturing
    e. commercial and service industry
    f. municipal wastes, total
        (1) sewage sludge
        (2) street sweepings

2. Quantity of solid waste by material, total
    a. garbage
    b. paper and cardboard
    c. grass, brush and prunings
    d. metals totals
        (1) ferrous
        (2) non-ferrous
    e. glass and ceramics
    f. plastics
    g. demolition and construction wastes
    h. ashes
    i. sewage sludge

COMPREHENSIVE STUDIES OF SOLID WASTE MANAGEMENT

Second Annual Report

PREFACE

NATURE AND SCOPE OF REPORT

The report herein presented is of the nature of a progress report covering the second year and the first two months of the third year of a comprehensive study of solid wastes management made possible by a Public Health Service Research Grant No. UI-00547-02 from the Environmental Control Administration — Bureau of Solid Waste Management to The Regents of the University of California.

The research plan on which the grant (originally, SW-00003) was based called for two phases of investigative work. The first phase involved the organizing of a multidiscipline research group and its participation in a data-collecting and data-evaluating activity. During the second phase, the group was to be divided into research teams and directed to a coordinated study of such aspects of the solid wastes problem as planning, economics, operations research, public health, and technology. Phase I and the initial activity of Phase II was reported in the First Annual Report [1] (SERL No. 67-7 dated May 1967).

The report herein presented is concerned with the progress of research by teams devoted to Phase II of the study during the period June 1967 to September 1968.

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Introduction
Evaluation of Problem
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TABLE OF CONTENTS

Page

Chapter

I. Introduction 1
  Need for Study 1
  Rationale of Study 1
  Objectives of Study 1
  Organization for Study 2
  Nature and Scope of Study 3
II. Reevaluation of the Problem 4
  Introduction 4
  Nature of the Problem 4
    The Problem in 1966 4
    The Problem in 1968 5
      Changes During the Period 5
      Emerging Concepts 6
      The Number One Problem 6
      Program Emphasis 7
      Collection System Problems 7
      Public Health Problems 10
  Evaluation of the Research Program 11
III. Planning 13
  Introduction 13
    Rationale 13
    Objectives of the Regional Solid Wastes Generation Model 14
  The Investigation 14

TABLE OF CONTENTS (Continued)

Chapter Page

Study Region 14

Specification of Variables 15

Definition of Functional Regions (Disposal Service Areas) 15

Location and Identification of Disposal Sites and Functional Regions (DSA's) 16

Development of Data on Solid Wastes Generation and Related Variables 17

Solid Wastes Generation 17

Collection of Solid Wastes Data from Disposal Site Operators 17

Estimation of Solid Wastes Quantities from Sources of Wastes and Wastes Multipliers 18

Sources of Wastes 18

Solid Wastes Multipliers 21

Residential Sources 21

Commercial, Nonmanufacturing, and Public Agency Sources 21

Industrial Sources 26

Agricultural Sources 29

Total Wastes Generated Within the Region 31

Employment 31

Population 31

Household (Residential) Income 38

Land Use by DSA's 38

Results of the Solid Wastes Generation in the Nine-County Bay Area 38

Public and Private Expenditures for Refuse Removal and Disposal 41

IV. Operations Research in Solid Wastes 47

Optimal Activity Locations 47

Determination of Optimal Wastes Flow Patterns 50

Optimization of Solid Wastes Treatment Plant Operation 51

Introduction 51

TABLE OF CONTENTS (Continued)

Chapter Page

Study Region 14

Specification of Variables 15

Definition of Functional Regions (Disposal Service Areas) 15

Location and Identification of Disposal Sites and Functional Regions (DSA's) 16

Development of Data on Solid Wastes Generation and Related Variables 17

Solid Wastes Generation 17

Collection of Solid Wastes Data from Disposal Site Operators 17

Estimation of Solid Wastes Quantities from Sources of Wastes and Wastes Multipliers 18

Sources of Wastes 18

Solid Wastes Multipliers 21

Residential Sources 21

Commercial, Nonmanufacturing, and Public Agency Sources 21

Industrial Sources 26

Agricultural Sources 29

Total Wastes Generated Within the Region 31

Employment 31

Population 31

Household (Residential) Income 38

Land Use by DSA's 38

Results of the Solid Wastes Generation in the Nine-County Bay Area 38

Public and Private Expenditures for Refuse Removal and Disposal 41

IV. Operations Research in Solid Wastes 47

Optimal Activity Locations 47

Determination of Optimal Wastes Flow Patterns 50

Optimization of Solid Wastes Treatment Plant Operation 51

Introduction 51

TABLE OF CONTENTS (Continued)

Chapter Page

Dual Service Rate Treatment Facility with Continuous Arrival of Wastes 52
General Description 52
Mathematical Formulation 52
Continuous-Rate Treatment Facility with Periodic Arrival of Wastes 52
General Description 52
Mathematical Formulation 53
Extensions 55
V. Economics 56
Introduction 56
Economics of Scale 56
Introduction 56
Importance of Economics of Scale 57
Analysis of Cost Data 57
Economics of Scale In Collection by Truck 59
Incineration 59
Transfer and Long-Haul Transport In Road Vehicles 61
Landfill Utilization 62
Discussion 63
Economics of the Low-Cost Biostabilization (Composting) System 63
Background 63
The Process 63
Land Requirement 63
Total Daily Production 64
Costs 64
Hauling 64
Refuse Grinding 64
Composting 64
Field Spreading and Tilling 65

TABLE OF CONTENTS (Continued)

Chapter Page

Land-Use Charges 65

Burial of Noncompostables 66

Summary of Costs 66

Comparison with Conventional Composting Methods 66

Economics of the Anaerobic Digestion Process 67

Introduction 67

Assumptions 67

Amounts of Wastes to be Treated 68

Grinding 68

Digestion 69

Volumes 69

Digester Costs 69

Maintenance and Miscellaneous Costs 71

Cash Value of Digester Gas 72

Volume of Gas Produced 72

Sale of the Gas 73

Summary of Costs 73

Discussion 73

Conclusions 75

Economics of Biofractionation 75

Preliminary Cost Estimate of the Proposed Microbial Cellulose Decomposition Process 75

Description of the Process Design Basis 75

General Process Description 76

Cost Factors 76

Net Waste Treatment Costs 76

Discussion of Process Economics 79

Economics of Wet Oxidation 79

Introduction 79

Process Evaluation 79

TABLE OF CONTENTS (Continued)

Chapter Page

Equipment Requirements 81

Costs 81

Conclusion 82

Economics of Pyrolysis 82

Introduction 82

Proposed Design 82

Discussion and Conclusions 82

VI. Public Health 84

Introduction 84

Relation of Solids Wastes Management to Disease 84

Role of Public Health in Solid Wastes Management 85

Nature and Results of Investigation 86

Procedure 86

Investigative Findings 87

Discussion 110

Research Needs 110

Future Work 111

VII. Anaerobic Digestion 112

Introduction 112

Objectives 112

The Investigation 112

Introduction 112

Development of Equipment and Procedures 113

Preparation of Raw Materials 113

Analyses 117

Experimental Series I: Addition of Green Garbage to Acclimatized Sludge Digesters 117

Procedure 118

Results 118

Conclusions 121

TABLE OF CONTENTS (Continued)

Chapter | Page

Experimental Series II: Digestion of Paper Pulp 125
Procedure 125
Results 125
Conclusions 130
Experimental Series III: Digestion of Combined Solid Wastes 130
Procedure 130
Results 134
Conclusions 137
Experimental Series IV: Addition of Wood to Digesters 141
Introduction 141
Procedure 141
Results 141
Conclusions 144
VIII. Composting 149
Introduction 149
Rationale 149
Low-Cost Biostabilization System 149
Objectives 150
The Experiments 150
Experimental Setup 150
Progress 153
IX. Wet Oxidation 154
Introduction 154
Rationale 154
Objectives 156
Experimental Approach 156
Phase I — Determination of Basic Reaction Relationships 156
Phase II — Oxidation of Organic Solid Wastes Materials 161

TABLE OF CONTENTS (Continued)

Chapter | Page

Phase III — Process Design 161
Results 161
Discussion 163
Future Prospects 169
X. Incineration — Pyrolysis 171
Introduction 171
Rationale 171
Objectives 172
Basic Demonstration Unit Design 172
Progress During Past Year 173
Future Prospects 175
XI. Biological Fractionation of Organic Wastes 176
Introduction 176
Rationale 176
Objectives 177
The Investigation 177
Organisms 177
Description of the Process 178
Development of Equipment 180
Experimental Work 180
Optimization of Enzyme Production 180
Maintenance of Enzyme Activity 184
Recovery of Enzyme 184
Dense Culture Technique for Rapid Decomposition 184
Summary 184
XII. Summary 186
Introduction 186
Research Activities and Findings 187
Planning 187
Operations Research 188

TABLE OF CONTENTS (Continued)

Chapter Page

Economics 189
Low-Cost Biostabilization (Composting) System 189
Anaerobic Digestion 189
Biofractionation 189
Wet Oxidation 190
Incineration-Pyrolysis 190
Public Health 190
Technology 191
Anaerobic Digestion 191
Composting 192
Wet Oxidation 192
Incineration-Pyrolysis 192
Biofractionation 192

APPENDICES

A. List of Disposal Sites 193
B. Definition of Disposal Service Areas 196
C. Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries 199
D. Solid Wastes Classifications by Point of Origin 216
E. Multipliers for Large and Small Firms 220
F. Population Data Sources 223
G. Land-Use Data 226
H. Determination of Cellulose in Sewage 231
REFERENCES 241

LIST OF TABLES

Table	Title	Page
1.	Conceptual Comparison of Utility and Natural Systems	9
2.	Detailed Tabulation of Comparable Wastes Figures, Population, Total and Average Per Capita Wastes	19
3.	List of Wastes Sources	20
4.	Residential Wastes	22
5.	Employment by DSA and by Wastes Source	23
6.	Multipliers for Nonmanufacturing Industry, Commercial and Public Facilities	26
7.	Industrial Multipliers	28
8.	Multipliers for Vineyards and Orchards	30
9.	Agricultural Source Units by DSA: 1966	32
10.	Agricultural Wastes by DSA, by Source: 1966	33
11.	Wastes Generation by DSA and by Wastes Source (tons per year)	34
12.	Population by DSA	37
13.	Solid Wastes Production in Terms of Disposal Service Area, Source, Population, Households, and Employment	39
14.	Examples of Combinations of Private and Public Collection and Disposal Services	42
15.	Privately Operated Disposal Sites: Revenues and Expenditures	44
16.	Publicly Operated Disposal Sites: Revenues and Expenditures	45
17.	Cost Per Capita Per Year for Digesting Refuse	74
18.	Cost Per Ton of Refuse or Garbage Digested	74
19.	Estimated Materials Balance for Proposed Cellulose Conversion System	77
20.	Major Equipment for Cellulose Conversion System	77
21.	Fixed Capital Estimate for Cellulose Conversion System	78
22.	Manufacturing Costs for Cellulose Conversion System	78
23.	Preliminary Economic Estimate for Pyrolysis-Combustion System of Disposal of Solid Wastes for a 200-ton/day Solid Wastes Capacity (Oven Dry Basis)	83

LIST OF TABLES (Continued)

Table Title Page

24. Public Health Evaluation of Domestic Wastes 89

25. Public Health Evaluation of Industrial Wastes 94

26. Public Health Evaluation of Agricultural and Food Processing Wastes 100

27. Public Health Evaluation of Commercial Wastes 104

28. Public Health Evaluation of Special Wastes 108

29. Cellulose Content of Primary Sludge Feed During Paper Pulp Digestion Experimental Runs 126

30. Daily Input of Cellulose to Digesters 126

31. Cellulose Destruction in the Digesters (Paper Pulp) 127

32. Efficiency of Paper Pulp Digestion 129

33. Percent Total Solids Reduction in Paper Pulp Digestion 131

34. Efficiency of Cellulose Reduction in Combined Wastes Digestion 139

35. Solids Reduction in Digesters Fed Monterey Pine Wood 145

36. Cellulose Decomposition in Digesters Fed Monterey Pine 146

37. Acid-Base Parameters in Wood-Fed Digesters 147

38. Gas Composition in Wood-Fed Digesters 148

39. Loading Rates for Shredded Refuse and Rough Compost on Experimental Plots 153

40. Typical Costs for Low-Temperature and Low-Pressure Wet Oxidation of Sewage Sludge 155

41. Summary of Wet Oxidation Reactions of White Fir Wood 162

42. Materials Balance for Wet Oxidation Reactions of White Fir Wood 164

43. Oxygen Consumption and Carbon Dioxide-Carbon Monoxide Formation in Wet Oxidation Reactions of White Fir Wood 166

44. Disposal Sites in Alameda County 194

45. Disposal Sites in Contra Costa County 194

46. Disposal Sites in Marin County 194

47. Disposal Sites in Napa County 194

48. Disposal Sites in San Francisco County 194

49. Disposal Sites in San Mateo County 195

LIST OF TABLES (Continued)

Table	Title	Page
50.	Disposal Sites in Santa Clara County	195
51.	Disposal Sites in Solano County	195
52.	Disposal Sites in Sonoma County	195
53.	List of Disposal Service Areas as Defined According to Census Tracts	197
54.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, Alameda County	200
55.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, Contra Costa County	200
56.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, Marin County	201
57.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, Napa County	201
58.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, San Francisco County	202
59.	Disposal Service Areas, Corresponding Truck Routes, and Census Tract Boundaries, San Francisco County	203
60.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, San Mateo County	204
61.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, Santa Clara County	205
62.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, Solano County	206
63.	Disposal Service Areas, Corresponding Disposal Sites, and Census Tract Boundaries, Sonoma County	207
64.	Solid Wastes Classification by Point of Origin	217
65.	Large-Firm Multipliers	221
66.	Small-Firm Multipliers	222
67.	Population Data Sources, Special Problems and Solutions by County	224
68.	Data Sources and Reference Period	227
69.	Comparison of Land-Use Data Code and Wastes Sources	228
70.	Land Use — BASS III: 1965	229

LIST OF FIGURES

Figure	Title	Page
1.	Realization for Period i	53
2.	Flow Diagram of a Generalized Continuous Wet Oxidation System	80
3.	Incubator with Controls for Stirring System and Temperature	114
4.	Digester Units and Stirring System Within the Incubator	115
5.	Digester Gas Collection Apparatus	116
6.	Efficiency of Green Garbage Digestion	119
7.	Morphological Variety of Microorganisms Found in the Digester Culture Fed Entirely on Sewage Sludge	120
8.	Morphological Variety of Microorganisms in the Digester Fed Entirely on Garbage	120
9.	Solids Reductive in Green Garbage Digestion	122
10.	Effect of Green Garbage Loading on Digester Acid-Base Equilibria	123
11.	Effect of Green Garbage Loading on Gas Composition	124
12.	Efficiency of Paper Digestion	128
13.	Effect of Paper Pulp Loading on Digester Acid-Base Equilibria	132
14.	Effect of Paper Pulp Loading on Gas Composition	133
15.	Efficiency of Combined Wastes Digestion	135
16.	Effect of Combined Wastes on Digester Acid-Base Equilibria	136
17.	Solids Reduction in Combined Wastes Digestion	138
18.	Gas Composition of Combined Wastes Digestion	140
19.	Gas Production of Wood-Fed Units	142
20.	Efficiency of Wood Digestion	143
21.	Small Refuse Shredding Facility Used to Prepare On-Campus Domestic Refuse for Composting or for Direct Application to the Experimental Plots	151
22.	Compost Drum, 5 ft Long by 6 ft Diameter, Batch Operation	151

LIST OF FIGURES (Continued)

Figure Title Page

23. Experimental Field Plots 152

24. Close-Up of the Plot Receiving 200 ton/acre/year of Rough Compost 152

25. Schematic Diagram of Batch Wet Oxidation Process 157

26. Instrumentation Complex for Monitoring and Recording Reaction Parameters 158

27. Reactor Extension and Agitator Drive in Assembled Form 159

28. Air Compression and Storage System 160

29. Total Carbon Distribution in Wet Oxidation Reactions of White Fir Wood as a Function of Temperature and Air Input 165

30. Oxygen Consumption and CO_2-CO Formation in Wet Oxidation Reactions of White Fir Wood as Functions of Temperature and Air Input 167

31. Oxygen Consumption and CO_2-CO Formation per 100 g Solubilized Carbon in Wet Oxidation Reactions of White Fir Wood as Functions of Temperature and Air Input 168

32. Schematic of a Two-Stage Pyrolysis-Combustion Unit 174

33. Schematic Representation of a Continuous Process for the Production of Protein and Carbohydrate from Cellulosic Waste Material 179

34. Schematic Diagram of Fermenter and Control System 181

35. System of Three Culture Vessels 182

36. Control Panel for Culture Equipment 183

37. Alameda County DSA's 208

38. Contra Costa County DSA's 209

39. Marin County DSA's 210

40. San Francisco County DSA's 211

41. San Mateo County DSA's 212

42. Santa Clara County DSA's 213

43. Solano County DSA's 214

44. Sonoma and Napa Counties DSA's 215

I. INTRODUCTION

NEED FOR STUDY

The need for comprehensive studies of solid wastes management that gave rise to the investigation upon which this report is based derives from man's delay in defining his environmental goals until the problems of living with his wastes had reached critical proportions. For a detailed evaluation of this need the reader is referred to the First Annual Report [1] on the investigation, in which the authors set forth at some length the nature of the solid wastes problem; its basis in tradition, urbanization, affluence, and ignorance; and the ways in which jurisdictional arrangements, economic concepts, social attitudes, and technology have delayed any satisfactory solution. It is particularly stressed in the report that citizens and public officials have historically shown little interest in investing money in solid wastes management; that unplanned and uncoordinated urban expansion has brought the urban, suburban, and rural sectors of many communities into intimate contact; that solid wastes management has become a regional problem involving the whole spectrum of wastes produced by industrial, agricultural, and domestic utilization of resources and products rather than of domestic refuse alone; that our national economy depends to an important degree upon the generation of wastes; that the technology of production of consumer goods is not significantly concerned with their ultimate disposability, while the technology of disposal has not been related to the total wastes except in the most primitive way; and that ignorance of the problem and of its feasible solutions persists at all levels of society.

RATIONALE OF STUDY

The rationale of the study, as set forth in the First Annual Report [1], involves three principal concepts.

1. That all wastes are destined to remain somewhere on the earth or in its atmosphere, hence the general problem of research is to find the optimum way to sequester wastes on the earth without interfering with man's freedom to use the earth's resources.

2. That "wastes" are more properly defined as residues of resource use which result from the application of current technology under present concepts of economics and social objectives.

3. That a program of research can simultaneously achieve many of the objectives of a needed educational program while contributing to the solving of jurisdictional, planning, economic, operational, and technological problems of solid wastes management.

The report then sets forth ten major specific concepts and illustrates graphically the seven ways in which solid wastes disposal is feasible.

OBJECTIVES OF STUDY

The general objective of the study is to contribute significantly through research, and through the knowledge gained in research participation, to an understanding of the systems, technological and human aspects of wastes management involved in utilizing the earth's natural resources with a minimum degree of degradation of the human environment. Pursuant to this general goal, the research program is directed to several more specific objectives, including:

1. To bring the competence of people in the wide variety of disciplines involved in planning, financing, and administering a community into effective combination with that of engineers and environmental health specialists in seeking solutions to problems in solid wastes management which are technically sound, economically feasible, and politically and socially acceptable.
2. To bring the techniques of modern operations research to bear upon the organizational problems of managing solid wastes on an area-wide or community-wide basis; and on the physical and logistic problems of collecting, transporting, and disposing of wastes.
3. To seek through experiments and other research techniques improvements in conventional methods of wastes disposal and the development of new procedures for reclaiming or recycling fractions of the refuse mass.
4. To identify and seek answers to problems involving man's health and well-being that may be associated with solid wastes and related to his use of land, water, and air resources.
5. To develop, through participation in research, greater understanding and knowledge on the part of engineers, planners, administrators, economists, public health specialists, and others who are confronted with the problem of solid wastes management in the course of their professional service to the modern urban-industrial-agricultural community.
6. To insure, through close coordination and effective communication with public and private agencies, the pertinence of research to real problems and the prompt availability of the results of research to professional practitioners.

ORGANIZATION FOR STUDY

The five faculty investigators noted in the Preface, representing the Sanitary Engineering Research Laboratory of the College of Engineering and School of Public Health on the Berkeley campus and the Department of Agricultural Engineering of the Davis campus of the University of California, were responsible for the overall management of the project. In the conduct and coordination of the research program, they were assisted by additional faculty members and professional researchers who took responsibility for various specific aspects, including:

Professor C. R. Glassey, Operations Research
Dr. D. I. Brink, Forestry
Professor C. R. Wilke, Chemical Engineering
Professor P. B. Stewart, Mechanical Engineering
Dr. S. A. Rao, Planning and Economics

Dr. Clarence G. Golueke, Chief Biologist of the SERL staff, served as project coordinator, with assistance from Mr. S. A. Klein, Assistant Specialist on the project staff. A total of 12 graduate students participated in the program; five doing work on doctoral dissertations in economics, forestry, chemical engineering, sanitary engineering, and operations research; two completing Masters' theses in Planning and Operations Research. As noted in the First Annual Report [1], close cooperation with the California State Department of Public Health afforded the project the benefits of its statewide survey of refuse management and its federally-financed demonstration project at Fresno, California. A similar arrangement with the Public Health Service made available the results of a survey of industrial solid wastes conducted by the Food Machinery Corporation under a federal grant.

NATURE AND SCOPE OF STUDY

As described in the First Annual Report, the study reported herein is directed to a number of related facets of solid wastes management conceived as subsystems in a comprehensive wastes generation and evaluation model developed by the project. To this end, coordinated research teams with overlapping staff personnel organized as noted in the preceding section are directed to specific aspects of the problem, including:

1. Planning on a regional scale, both for the wastes-generating potential of alternate types of development and the land requirements of disposal of such wastes.
2. The operations research aspects of wastes management, including the logistics of assembling wastes and moving them efficiently and economically through an urban complex; and the nature of systems suited to regional or community-wide wastes management and disposal.
3. The economics of alternate planning, operating, and disposal schemes.
4. The possibilities of improving technology for disposing of all or selected fractions of the total solid wastes of a community, with special research emphasis on the processes of:
    a. Anaerobic digestion
    b. Wet oxidation
    c. Biofractionation
    d. Pyrolization-incineration
    e. Composting
5. The public health implications of solid wastes management.

Investigative work on each of these several aspects is included in the scope of the study.

II. REEVALUATION OF THE PROBLEM

INTRODUCTION

In order that any research program maintain its relevance to the problems which originally justified its initiation, it is necessary to reevaluate both the program and the problems themselves from time to time. This is particularly true in the solid wastes field where management of physical materials (wastes) is more a matter of political accommodation, systems engineering, logistics, economics, and technology than of discovery of basic scientific facts. This is not to say that there is no place for fundamental research related to wastes disposal, but, rather, that it should be clearly understood at the outset of any project just what achievements will constitute its success; and the project should be reviewed from time to time for evidence of "drift." Projects intended to yield practical results are much more likely to drift off into exploration of scientific minutiae than are narrowly-conceived scientific projects likely to produce practical solutions instead. There is also the danger in the practical project that the point where economics becomes limiting within an acceptable time span will pass unnoticed unless the investigator is particularly alert to this pitfall.

But assuming that neither drift nor demonstrable economic infeasibility befalls a well-managed project, the very fact that research moves slowly at best imposes the risk that the project may continue to seek the answer to a question long after the time when the question ceases to be considered worth the asking. In the case of solid wastes, where progress toward solution of problems has been glacier-like in its advance because of man's inability to see the problem or his disinclination to recognize it, there is little reason to fear that the answer will outrace the quest. Nevertheless, the rapid rise of national concern for environmental quality and the growing intensity of local alarm over refuse disposal problems might render such a judgment invalid or generate new problems of solid wastes management which either overwhelm the old in importance or require resolution before the old ones become again relevant.

In this section of the report, attention is directed principally to a reexamination of the status and nature of the solid wastes problem and to the background for evaluation of the ongoing research program.

NATURE OF THE PROBLEM

The Problem in 1966

When the project herein reported was initiated in 1966, Public Health Service activity in the field of solid wastes had just been given major status under the Solid Waste Disposal Act — the common designation of the amendment to the Clear Air Act signed into law by President Johnson in October 1965. As noted in the preceding chapter (under Need for Study), the most urgent problems of solid wastes management at that time were the outgrowth of deficiencies in planning, politics, economics, technology, and general public awareness. Specifically, essentially no plan for land use could be found in which the planning agency had proposed to dedicate any land to solid wastes disposal. There was a tendency to consider land too valuable for refuse fills or composting activities if it could conceivably be utilized profitably for any other purpose.

Politically, each jurisdictional unit was organized to handle only its own local affairs, which included the distasteful responsibility of getting rid of its wastes. Except in a few larger cities, this task was commonly given a minimum of concern; and under the then prevailing concept of land use, the ancient idea of disposal by exporting wastes beyond its own jurisdictional boundaries prevailed in most communities. Moreover, the economic feasibility of even this method was viewed with a quite conservative attitude.

In addition, traditional public concern was primarily for municipal refuse disposal, with other producers of wastes expected to solve their own disposal problems. Technology involved land disposal by procedures ranging from open dumps to sanitary landfills; incinerators of varying degrees of acceptability; and a process of composting with a history of commercial failure.

In 1966, a crisis in solid wastes disposal was already mounting as plastics and other undegradable materials became more common; the nation increasingly included aesthetics and quality of life in its environmental goals; and land once considered worthless came to be highly valued for its resource potential and ecological importance.

The Problem in 1968

Changes During the Period. During the period 1966 to 1968, the solid wastes program of the federal government stepped up its activities until in the fiscal year 1968 it conducted and supported some 15.5 million dollars of research, training, and demonstration projects. Simultaneously, numerous communities, under the stress of unresolved local problems of solid wastes disposal and the hope of possible federal assistance, took stock of their own unhappy situations. Private enterprise likewise began to take an eager interest in the way in which systems and hardware might be involved in any resolution of the problem. Many planning agencies became aware of the land use planning deficiency in relation to solid wastes management schemes. And local governmental units became conscious of the need and the pressure for regional jurisdictions to deal with solid wastes.

All of the foregoing activity had some impact on the problems identified in 1966, and on bringing into sharp focus a number of related problems. The effect in resolving the solid wastes problem of 1966, however, was more apparent than real. No new authority accrued to planning agencies in general. Awareness of solid wastes tended to add only one more aspect to plans which historically had no effect in law. In any event, the information and data needed for predicting the solid wastes generating potential of land dedicated to any use pattern remained elusive; and public sentiment and organized group pressure against landfills in many places further constrained the possibilities. The gross effect of all this was to make the land-use planning problem more acute in 1968 than 1966.

A similar situation developed in relation to jurisdictional arrangements. Awareness of the need for regional solutions brought into play those forces of provincialism and local jealousy, as well as those questions of taxing power, which must be reckoned with before effective action is to result, thus compounding the problem of regional solutions to solid wastes management problems. Investigative activity and awareness of jurisdictional and planning problems tended to bring into focus the fundamental economic realities of the situation. This, if anything, tended to harden the concept that economics is the real roadblock to action, and brought out clearly the near impossibility of finding reliable cost data on which to make future projections.

In the realm of technology, the two-year period of 1966-68 saw no profound changes. Research continued apace along a number of lines and pursuant to a number of ideas which might prove to have technical and economic possibilities for managing or utilizing various fractions of the overall solid wastes mass. A number of significant demonstrations likewise got underway during the period. Promotional activity, particularly in the realm of incineration, was greatly intensified. Some technological progress was, of course, made in the interval, but not enough to render invalid in 1968 those problems of technology confronting the community, the researcher, or the engineering profession in 1966. Very little, if any, progress seems to have been made toward a public realization that incineration is not a total answer to its problem of land disposal of solid wastes.

Leaving to later paragraphs a discussion of effects on the relevance of the project herein reported, it is here concluded that awareness rather than resolution characterized the changes in the 1966 problems during the two years which followed. The period did, however, call attention to other facets of solid wastes management which, although not unobserved in 1966, will require greater attention in the years immediately ahead. To them we now turn attention.

Emerging Concepts. One of the most elusive facets of the problem of solid wastes is the shifting cultural attitudes which tend to disorient the public to rational solutions and to compound the already considerable task of education and communication. Solid wastes management is one of a growing number of aspects of environmental control in which what people will support, or at least tolerate, may be the deciding factor in determining the feasibility of otherwise possible solutions. One of the major causes of this phenomenon is the changed environmental goals which have emerged in recent years; particularly, the shift in emphasis from the control of "pollutants" in the environment to the maintenance of "quality of the environment" or of air, water, and land resources. Regardless of the desirability of this new objective, it is based on idealistic and aesthetic considerations with which no one can disagree, and so makes it more difficult to overcome the stubborn realities of dealing with unwanted residues.

An outgrowth of the "resources quality" approach, or the corollary to it, is the growing concept that considerations of ecological streams, preservation of habitat, maintenance of natural environments, and similar factors, preclude the dedication of much low-lying land to the purpose of wastes disposal, regardless of alternatives. This adds to an unwillingness to accept refuse disposal as a beneficial use of land and so contributes to the persistent pretense that some process such as incineration, composting, or digestion, which will degrade organic matter, is an alternative to landfill, and so one of the oldest and most stubborn problems of solid wastes management is kept alive if not, indeed, worsened, no matter how often or carefully it is explained that some 50 percent of refuse must, and will, come to rest on the land.

Compounding the problem is a second emerging concept — the concept of "environmental insult" or "land pollution." Although this may seem a logical extension of established concern for air pollution and water pollution to the last, (land), of the three basic resources (air, water, land), and has an easy appeal to the citizen, it poses a new problem in environmental control. Specifically, solid wastes differ from air and water pollutants because they generally have no tendency to diffuse into the land resource. The act of rejection of a physical object which converts it from a "resource material" to a "waste" involves its deposition on the land. There it remains essentially in its original concentration until someone picks it up and transports it to another resting place more acceptable to man. In contrast, the "pollutant" rejected to the air or water is at once introduced into a natural transport system where, by diffusion, it contaminates other sectors of the receiving resource and is translated to other areas distant from its point of origin. The fundamental characteristic of air and water pollution makes possible a control program based on regulation of permissible concentration in the resource. A regulatory approach to the so-called "solid wastes," however, is infeasible. Physical "management" of the discarded object, including the provision of a transport system, is required. Although well known to engineers and scientists concerned with the solid wastes program, the emerging popular idea of "land pollution" introduces a relatively new aspect to the problem of environmental control or of gaining public support for some control measures.

The Number One Problem. Throughout the period covered by this report, and especially during the year 1968, the project staff inquired of public officials, "What is the number one problem of solid wastes management?" At the local level, in smaller communities, the answer often ranged from finance to labor; but in all large communities, where the problem of solid wastes management in the United States is most urgent, the answer was, invariably – "Finding any location at which to do whatever it is you need to do, whether it be a transfer station, an incinerator, a landfill, a processing plant, or even a transport route." As noted in the preceding sections, some of this attitude derives from emerging concepts of environmental quality; some from historic inattention to solid wastes as a land worthy of consideration. Property value depreciation, noise and hazard of passing trucks, and general dislike for "garbage," especially someone else's, are among the identifiable reasons. In some cases, citizens have lain down in the streets to force rerouting of collection vehicles; and at least one city threatened to sue in an attempt to prevent a refuse-laden train from passing through it on its way to a distant disposal site. Although the Los Angeles County Sanitation Districts have done a remarkable job in gaining public acceptance of their well-conceived and executed landfills, many other communities are persuaded by the haphazard routines permitted in their environs in the past that "sanitary landfill" is merely a euphemism for "dump." In any event, there seems little doubt that the number one problem of solid wastes management in 1968 is the matter of site, or that this problem is more acute in 1968 than in 1966.

Program Emphasis. Major inventories of solid wastes problems and facilities conducted by the federal solid wastes program, the California State Department of Public Health, and various localities have demonstrated that some 80 percent of the cost of solid wastes management is in the collection and storage phases. At the same time, it was reported that most of the federal expenditure for research and demonstration is directed to the problem of disposal. This in 1968 introduced a question concerning program emphasis which is of concern to the authors of this report in their project evaluation.

Explanation and justification of the priority of disposal is forthcoming from public officials who note that rather than tolerate wastes indefinitely in the streets the public will find some way to provide money needed to alleviate the problem. With money it is possible to employ men to pick up the refuse and to purchase trucks on which to load it. But to find any place in the environment where the public will permit the trucks to be unloaded is an all but insoluble problem. This is, of course, but another manifestation of The Number One Problem cited in the previous section. It does not, however, evaluate the problem of collection adequately for the objectives of this chapter.

Collection System Problems. Perhaps the problem of solid wastes management which has assumed greatest proportions since 1966 is that of the collection system and its associated on-site storage of wastes. Logic suggests that if the cost of solid wastes management is to be reduced or minimized as the cost of disposal increases, a careful study should be made of that portion of the total system where the most money is being spent. In this aspect of the solid wastes problem, three principal questions arise:

1. What is the problem of on-site storage?
2. What is the major item of cost in the collection system, and how can it be reduced?
3. What can be done with the system itself?

In the discussion that follows, it is intended to identify the problems rather than to suggest their ultimate solutions.

Although householders find storage of refuse on their premises a bother or perhaps a nuisance, the principal complaints come from hotel, high-rise apartment, and other commercial building owners or managers. The problem is that large volumes of refuse are a nuisance and an expense, particularly in that storage ties up building floor space which in some cases is valued at several thousand dollars per square foot. The question, however, is not so much how to provide and manage on-site storage as how to develop a collection system that makes on-site storage unnecessary.

The major item of expense in the collection system is reported to be labor. More than any other utility or public service, refuse collection depends upon a relatively large labor force. Historically, this labor has been generally low-priced, at least in comparison with that of the building trades, for example. In an increasingly opulent society with a strong status concept attending man's function in that society, some communities in 1968 reported difficulty in getting men to take jobs on the sanitation force. Others reported this to be no problem but, nevertheless, 1968 saw a growing tendency for public employees to form unions and to go on strike without evident penalty of laws forbidding strikes by public servants. In such diverse cities as New York and Memphis, it was made evident by sanitation workers that labor costs are destined to increase rather than to decrease in the coming years. The problem then becomes one of finding a way to attract labor to sanitation jobs; to provide pay and other incentives sufficient to keep men reasonably happy and productive, so that service is not interrupted; and, at the same time, to keep the cost of refuse collection in scale with that of other municipal services in terms of output of product.

Some individuals officially concerned with developing programs designed to solve problems of urban deterioration envision public subsidy to put labor to work. Refuse collection has been cited as a natural area for such a program because of its traditional need for large numbers of laborers. There is, however, growing reason to doubt the validity of the sociological assumption underlying this proposal, and to suggest that, as in the case of on-site storage, the problem is most likely to become one of devising a collection system which does not depend upon large numbers of men for its operation.

The problems of the collection system, especially that of changing it to a low-labor operation without on-site storage, are unique. In fact, the collection system as a system is without parallel in either municipal utilities or in nature. This is true as regards such aspects as 1) nature of inputs; 2) input energy potential; 3) direction of flow; 4) continuity of function; and 5) labor input to volume output ratio.

If municipal and natural systems, which involve either in concept or in physical configuration a main trunk or stream branched into myriad small inlets or outlets, are compared with the existing solid wastes collection system, the uniqueness of the latter is at once evident. Furthermore, it takes on an aspect of improbability which makes questionable its long-term survival.

Table 1 summarizes some of the principal system characteristics worthy of further comparison.

From an examination of Table 1, it is evident that only sewers and telephone systems and such natural systems as streams and growing plants function by incremental inputs at multiple points as does the refuse collection system. Water, gas, and electrical systems function by applying pressure in the main trunk by means of mechanical equipment rather than by hand labor.

Delivery systems tend to function as reverse collection systems, with a high labor-to-output ratio. The volume of commercial delivery systems is, however, small, and the customer pays the cost in his milk or merchandise bill. In the case of the U. S. mail delivery system, where the labor input is also high, the system is kept from failure only by a subsidy which spreads the cost to the general taxpayer on a national scale. By analogy with the mail delivery system, the refuse collection system as now conceived may be expected to fail in the long run unless the labor-to-output ratio is reduced, or, the fact of excessive labor cost is recognized and accepted by the public.

TABLE 1

CONCEPTUAL COMPARISON OF UTILITY AND NATURAL SYSTEMS

System	Nature of Inputs	Input Energy Potential	Direction of Flow	Continuity of Function	Ratio Labor Input to Volume Output
Water Supply	Mass input to main trunk	Pressure in main trunk	Main trunk to multiple points	Continuous and variable	Very low
Gas	Mass input to main trunk	Pressure in main trunk	Main trunk to multiple points	Continuous and variable	Very low
Electricity	Mass input to main trunk	Pressure in main trunk	Main trunk to multiple points	Continuous and variable	Exceedingly low
Sewers	Increments input at multiple points	Tension by gravity	Multiple points to main trunk	Continuous in main variable to discontinuous inputs	Essentially none
Telephone	Increments input at multiple points	Pressure imposed at multiple points	Multiple points to main trunk	Continuous in main variable to discontinuous inputs	Low
Flowing Stream	Increments input at multiple points	Tension by gravity	Multiple points to main trunk	Continuous and variable	--
Growing Tree	Increments input at multiple points	Tension in main trunk	Multiple points to main trunk	Continuous and variable	--
U. S. Mail Delivery Milk Delivery Parcel Delivery	Mass input to main trunk (Customer delivery system)	Pressure in main trunk	Main trunk to multiple points	Discontinuous and periodic	High
Refuse Collection	Increments input at multiple points	Pressure imposed at multiple points	Multiple points to main trunk	Discontinuous and periodic	High

Assuming the continuance of existing system characteristics, the problem of labor reduction in solid wastes collection systems has limited prospects except, perhaps, by the adoption of one-man vehicles, as is presently under study, or by some as yet unconceived alternative. A study of the problem of labor, however, might well begin with a comparison of labor costs for various municipal departments — e.g., water, gas, electricity, sewerage, buildings, parks, etc. — to establish definitely the comparative labor-to-output ratios of refuse management and other public works activities.

If a change in system concept rather than in simple labor investment is assumed, the problem becomes one of finding a feasible alternative to the present system. Returning to Table 1 and considering alternatives, only the sewer system among the utilities involves incremental inputs at points of origin. However, since the points of origin of sewage and solid wastes are the same households, two possibilities appear: 1) discharge of solid wastes to the sewer, or 2) development of a refuse collection system which in concept is analogous to the sewer system. The first of these is already partially in practice as a result of widespread use of household and restaurant garbage grinders. The question of what greater fraction of the total mass of refuse might be ground to the sewer has not yet been fully answered, but it is well known that an appreciable fraction of household wastes cannot be disposed of via the sanitary sewer. Thus, the second must be considered for some fraction of refuse.

The concept of a collection system in which inputs are made at multiple points by the householder or other generator of wastes and transport results from tension in the main trunk is rationally feasible if tension is imposed mechanically rather than by gravity. This type of a system is, of course, in limited use outside the United States. Problems yet to be resolved, however, include economics and the range of solid wastes fractions that can be transported with low-pressure air as the transporting medium.

A collection system in which air or water pressure rather than tension is imposed is not a hopeful idea. Attempts to develop a sewer system pressurized at each household have failed for reasons obvious to anyone familiar with pumping problems, although pressurized transport along a limited number of branches in a main trunk sewer is a well-established practice. In solid wastes management, it is feasible also, but introduces the added problem of noise, dust, and site location of grinding and pumping stations, and does not solve the problem of collection and delivery to such input points.

From the foregoing considerations, it may be concluded that, although there is good reason to direct major attention to the problems of refuse disposal which remain unsolved in 1968, very difficult problems persist in the collection aspect of solid wastes management.

Public Health Problems. The problems of public health associated with solid wastes management fall into a special category in which potential rather than immediately recognizable crisis is the distinguishing characteristic. Three general classes may be identified:

1. Problems which are reasonably well solved, but remain solved only by constant vigilance.

2. Problems which are unsolved, but are incapable of resolution independent of technological, political, and planning problems.

3. Problems which remain either unidentified or unevaluated in relation to other environmental hazards.

Problems which might be included in the first category occur in every aspect of solid wastes management from on-site storage to ultimate disposal. They include such matters as production of flies, mosquitos, and other insect vectors; harboring of rats and other rodents; nuisance of blow-about of paper and other refuse, of smoke and odors from burning fills, and dust from transfer or disposal operations. Such problems are, of course, timeless. They were recognized and attacked by health department activities long before 1966 and may be expected to continue long after 1968. The overall problem they impose on health agencies is that of eternal vigilance and the exercise of authority to control them to an acceptable degree. At no time can they be eradicated completely; hence their potential to degrade both human health and man's environment remains a characteristic of solid wastes quite as real as its physical aspects.

The second class of problems include both physical and psychological hazards. Refuse collection is known to be one of the most hazardous of occupations because men are required to lift and carry heavy loads in congested traffic situations, and to perform duties in dust that may carry bacteria, viruses, or inorganic particles which may have serious physiological effects. More subtle and less understood problems are involved in the close contact of humans and refuse in overcrowded urban environments. The effect on man's health is of constant nuisance and a degraded environment is a problem of public health concern which, however difficult to identify, cannot be resolved separately from other problems, some of which are involved with solid wastes management. Similarly, the occupational hazards of physical injury can be minimized by public health activities, but the problem itself can be resolved only as problems of collection and disposal are resolved with reduction of physical hazards as one of the objectives of the resolution. A similar situation exists in the case of air pollutants resulting from incineration, and the noise and congestion from the collection operation. Little change in this type of problem from the public health viewpoint has occurred in the past two years, hence concern must continue into the future.

Problems falling into either of the first two classes cited call for vigilance and supervision on the part of health authorities. Research, however, is more directly concerned with vector control, occupational health, and occupational medicine than with solid wastes management *per se*.

The third category of problems involves both medical and solid wastes management aspects. First, it is necessary to find that hazards to health exist in a vast spectrum of ever-changing products of industry which may appear in solid wastes. Therefore, the problem is to determine whether such materials constitute a hazard to workers who handle solid wastes, or may escape from the disposal process to become a danger to the public health. In case such hazards do indeed exist, the problem then becomes one of evaluating the risk involved in comparison with other environmental hazards; and, finally, of establishing values which constitute the limits of acceptable risk and devising ways to reduce the risk to such limits. Because the answer to such questions depends upon the simultaneous advance of research in medical toxicology, solid wastes management procedures, and environmental interrelationships, the questions persist in 1968 and may be expected to continue into the indefinite future.

EVALUATION OF THE RESEARCH PROGRAM

The research herein reported was directed to the problems of solid wastes management identified as valid in 1966. Five areas of investigation – planning, economics, operations research, technology, and public health – (see Chapter I, Nature and Scope of Study) constituted the program. Assuming as correct the judgment of the authors that the problems of solid wastes management to which the research was directed initially persisted throughout the second year of study, evaluation of the program is appropriate along four lines:

1. Continued relevance to solid wastes problems
2. Relative scope of the program and the overall problem of solid wastes management
3. Progress toward program objectives and solutions to the problem
4. Economic feasibility of various aspects of the program

On the basis of familiarity with the program, and an evaluation of it against the problems discussed in preceding paragraphs, it is the general conclusion of the authors that the research effort remained relevant to the problem of solid wastes management throughout the period reported. In Chapters III through XI which follow, progress is reported on various aspects of the program and specific conclusions are presented concerning relevance and scope. In Chapter V estimates of the economic feasibility, particularly of technological aspects of the program, are presented. These more detailed evaluations of the program are expected to furnish guidelines for further work on the project, and perhaps suggest to other researchers some areas to which investigative work might be directed.

III. PLANNING

INTRODUCTION

The long-term objectives of the planning team as set forth in the First Annual Report [1] of the project were as follows:

1. Development of structural models of wastes generation and obtaining the required data on solid wastes and other related variables with reference to a particular study region.
2. Exploration of the implications of changes in transportation and disposal technologies on solid wastes management and resources use in the study region.

Pursuant to these objectives, the first year of study (1966-67) was directed to a pilot study of wastes generation in Santa Clara County, California, in order to give definite form and content to the research method and objectives.

During the second year of study (1967-68), herein reported, investigative work was directed to several aspects of the wastes management problem. The objectives and methods of approach were tested against the realities of the situation and accordingly modified to suit the contingencies of research. Inasmuch as the development of some of the facets of the work hereinafter discussed are incomplete, the analysis of them is necessarily carried on into the third year (1968-69) of the project and hence the subject of a subsequent report.

Rationale

The complexities which beset solid wastes management suggests heuristically a need for regional or subregional approaches which can come to grips with the real problem and can lead to long-lasting solutions that are both efficient and satisfactory to the community at large. Before a regional system for disposal of solid wastes can be devised, however, it is necessary to have accurate information concerning generation of the wastes, i.e., of the quantity, source, composition, distribution, and variability of solid wastes.

Solid wastes are inherently integrated into the total problem of air and liquid wastes pollution. The burning of solid wastes increases air pollution; the use of garbage grinders increases the load on the liquid wastes disposal system. On the other hand, measures undertaken to abate the air pollution problem or to decrease the output of liquid wastes usually result in an increase in the quantity of solid wastes that must be handled. Thus, the generation of solid refuse not only is a function of the existence of households and municipalities, it is a consequence of all productive processes. Business, industry, and agriculture all generate solid wastes, and therefore the source should be identified under categories such as "households," "type of commercial, industrial, or agricultural activities," or other appropriate categories of generators of wastes. For decisions regarding the feasibility of disposal methods, composition of wastes must be further distinguished by type (garbage, rubbish, street refuse, etc.) and by physical and chemical properties (caloric value, nitrogen content, etc.). In addition, the need exists for estimating significant relationships that explain the amount and types of wastes generated in a given region based on comparable data relating to wastes generation and specific wastes generators. In order to specify the various data requirements in detail and to formulate the specific relationships to be estimated, it is necessary to devise a model-building framework that is conceptually sound and at the same time operationally feasible for a given region. Also, since standards of solid wastes management depend on criteria based on aesthetic values, public health, and economic efficiency, it is necessary that these constraints be effectively recognized within the model. With an awareness of such social and political aspects, alternative solutions to the problem can be developed with the aim of making it possible to select an optimization program. Furthermore, the differences in the future economic development of the region will have both qualitative and quantitative effects on the amount and types of solid wastes that must be handled within the system in the future.

Thus, in recognizing and establishing a regional solid wastes management system, it is imperative to formulate the initial data base with great clarity and consistency so that the system is operationally feasible and subject to revision whenever there is a structural change in the system. The specification of the relevant variables will be instrumental in discerning the regional differences in solid wastes management systems and sets the stage for further analytical research work. The aggregation of variables should be governed both by theoretical necessity and data availability. After the variables in the system are stipulated, the interrelationships between the amount of solid wastes generated and other concomitant variables should be estimated through structural equations of the model framework.

Objectives of the Regional Solid Wastes Generation Model

There are two principal objectives of the regional solid wastes generation model. The first is to develop a comprehensive, factual basis for the quantitative aspects of the regional wastes management system by giving due consideration to the spatial and functional nature of the region. The second is to use this factual base as the primary source of data in analyzing and estimating future volumes of solid wastes that would be handled within the system.

The ultimate goal of the analysis is to provide any given region with generalized methods of approach for arriving at a solution to the solid wastes problems within its functional boundaries. While it is possible to develop a theoretical framework with very little practical significance, the need today is to incorporate many of the systems analysis techniques into a comprehensive model that will give solutions capable of testing against the levels of data that are presently available. Traditional methods of recording data on amounts and types of solid wastes generated by the scavenger companies thus far have precluded a thorough analysis based on theoretical grounds. By necessity, the method at present should conform to the available body of data. A systems analysis approach based on existing data will facilitate a more thorough understanding of the solid wastes management problem than heretofore possible, and will provide insights into the various aspects of the problem which hitherto have been considered only on the periphery.

THE INVESTIGATION

Study Region

To test the validity of the regional model, an area of presently fragmented jurisdictions was chosen which encompasses most of the complexities of the wastes management problem. Because of its nature and proximity, the nine-county* San Francisco Bay Area region was selected as the operational area. The planned approach is to collect and correlate data on the types and quantities of solid wastes generated in the Bay Area, along with data on the wastes generators, and attempt to explain the interrelationships among them for further study and analysis.

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*Alameda, Contra Costa, Marin, Napa, San Francisco, Santa Clara, San Mateo, Solano, and Sonoma counties.

Specification of Variables

Wastes generation is a consequence of a variety of economic, geographic, and demographic factors, and each category of wastes may be associated with one or more explanatory variables. The major variables explaining wastes generation are population, income, employment, and land use. These and other less significant variables can be used to develop cross-correlations that will identify their relationships to the various categories of wastes and thereby facilitate effective projections of solid wastes volume.

In an ideal analytical model, every conceivable interrelationship between sources and types of wastes, and the activities that might affect the generation of the wastes, would be set forth and tested. While cost constraints and data limitations dictate that the actual dimensions of the model may be less than ideal, the specification of relevant relationships should be as complete as possible. A particular case study may aggregate the relationships to data needs, but the theoretical formulation should be available for a more detailed analysis as additional data on solid wastes are developed.

According to the initial research plans as set forth in the First Annual Report, five major sources of wastes were recognized, namely, household, commercial, manufacturing, agricultural, and special. The plan was to collect data on the total amount of solid wastes generated by these major sources, and to relate the wastes generation to corresponding explanatory variables such as population, income, employment, and land use by type of manufacturing, commercial, or agricultural activities within the study area. Had data on solid wastes generation been available by sources of wastes, a regression study of the relationships among the types of wastes (as the dependent variable) and other explanatory variables would have been carried out. However, the data on solid wastes generation from the various sources were not fully accounted for, even though special efforts were made to supplement the data obtained from disposal site operators. Because of the contingencies of the research and of the operational characteristics of the San Francisco Bay Area solid wastes study, the intended approach had to be modified.

The present modified approach — somewhat less idealistic than the original — consisted in developing the data needed on solid wastes generation from the source units and wastes multipliers. In so doing, the present method preempted the use of regression analysis of wastes generation. However, it calls for the recognition of important explanatory variables for each of the types of wastes to be considered in the study.

As a result of this modification, the wastes sources have been recognized in greater detail than was originally contemplated. Each source of wastes is measured by the size of the explanatory variables, e.g., residential wastes sources by households or population, commercial and industrial wastes sources by employment, agricultural wastes sources by acres of land used, number of trees per acre, and number of animals per acre, etc.

The various steps involved in developing solid wastes generation can be briefly stated as follows: 1) definition of functional boundaries, 2) collection of data on source units, and 3) development of appropriate wastes multipliers by type of economic activity.

Definition of Functional Regions (Disposal Service Areas)

To develop data on solid wastes and related variables on a uniform basis, it was necessary to define a set of functional geographic units into which the study region (the nine-county San Francisco Bay Area) could be divided. Since this division is instrumental in explaining the interrelationships between several variables, it was desirable to choose the smallest geographic unit so that a large number of independent observations could be developed for analysis.

The 1960 Census tracts (boundaries) have been and are being used as primary units in many empirical studies since they provide an initial data base for building up various economic data such as population, employment, and land use. However, while data on demographic and economic elements are available by Census tracts for the recent period 1965-66, corresponding data on solid wastes generation are conspicuously absent for such small geographic units. It would have been ideal if data on solid wastes generation had also been available by Census tract, since such a situation would have provided 750 or more observations for the present study.

Inasmuch as the use of Census tracts as primary geographical/functional units for wastes disposal was preempted by the paucity of solid wastes data, larger units consisting of groups of Census tracts (or parts thereof) were considered as the primary functional boundaries for analysis. Consequently, the available data on explanatory variables such as population, employment, and land use had to be aggregated spatially to correspond to the larger units defined as the primary functional boundaries. These primary functional boundaries, designated in this study as "Disposal Service Areas" (DSA's) form the basis for developing comparable data on all variables for study and anlysis. The DSA, as defined in this study, transcends all political boundaries (city or county) and establishes functional boundaries. This definition serves the purpose of establishing mathematical relations among wastes generation and other variables. The definition of an individual DSA is a nebulous one, as are all functional boundaries, and therefore it must be brought up-to-date if and when a change occurs in the nature of the function it represents.

Location and Identification of Disposal Sites and Functional Regions (DSA's)

Before actually delineating the functional boundaries (DSA's), it was necessary to locate and identify each and every solid wastes disposal site that receives wastes. Using the information developed by the California State Department of Public Health, a complete list of disposal sites was made and located on the county maps. These are given in Tables 44 through 52 in Appendix A.

Following the location of the disposal sites, the next step was to define the disposal service areas into which the study region could be divided for developing the primary data. The actual drawing of boundary lines for each DSA was done as follows: If a disposal site received wastes generated from one or more Census tracts (or parts thereof), that region was defined as a disposal service area. In situations in which two or more disposal sites receive wastes from two or more overlapping boundaries, and it was impossible to split the boundaries meaningfully, a single disposal service area was defined to consist of that total area. In other cases, the Census tracts were split between different disposal service areas, since it was possible to identify these parcels. Thus, the amount of wastes deposited in the site (sites) is always made comparable to the wastes generators with reference to the functional boundary (DSA) as the basis, thereby eliminating any arbitrary splicing of boundaries. For the purpose of this study it was possible to divide the study region (nine-county San Francisco Bay Area) into 42 functional boundaries. These boundaries, as identified by the Census tract codes, are given in Table 53 in Appendix B and in Figures 37 through 45 in Appendix B.

Problems encountered in defining disposal service areas for the nine Bay Area counties generally stemmed from two primary sources. The first source was the multiple-county use of a particular disposal site. This practice necessitated the formation of "cross-county" DSA's. The second was the splitting of Census tracts to correspond to collection boundaries when the scavenger company collection routes did not coincide with Census tract boundaries.

After a careful and detailed consultation with the California Department of Public Health and local city and county public health agencies, a consistent set of boundaries was established. The locations are shown in Appendix A; the allocation of disposal sites by functional boundaries in Appendix B; and the detailed list of Census tracts are given in Tables 54 through 63 in Appenxid C. Once the functional boundaries were defined, a systematic approach to data collection was required to maintain the standards of consistency, reliability, and comparability. The approach was formulated after a considerable effort had been made to determine the appropriate method of data retrieval given the constraints of time and costs. Since very little time-series data on solid wastes were available on a comparative basis, only spatial data on a cross section basis were incorporated into the model.

Development of Data on Solid Wastes Generation and Related Variables

Solid Wastes Generation. The development of complete and consistent data on solid wastes generated in the study region by functional regions (DSA's) and type of wastes generating source is of prime consideration. Data on wastes generation and disposal are being collected by public health agencies through on-site interviews with disposal site operators and with officials of the scavenger companies that collect refuse in the region. Although a mailed survey was conducted on a pilot basis in one of the counties (Santa Clara, California) to determine data collection procedure, it was later deemed appropriate to coordinate our own data collection efforts with those of the California State Department of Public Health. These initial plans have been described in the First Annual Report [1]. According to the agreed-upon plan, the data on solid wastes generation by functional boundaries were to be collected by the California Department of Public Health as part of their ongoing studies and supplied to this project.

Collection of Solid Wastes Data from Disposal Site Operators. The actual data collection procedures used by the California Public Health Department involved a specific timetable for interviewing and surveying particular counties. Accordingly, the nine Bay Area counties were surveyed by the Public Health Department at different times.* The Santa Clara county survey was completed in April, surveys of Contra Costa and Marin in May, and of Solano and San Mateo counties in June of 1967. The survey of Alameda was finished by the end of September 1967. The variation in reference periods, together with certain inherent data difficulties, gave rise to some incomparabilities which had to be reconciled before the data could be properly analyzed.

Each of the operators of nearly 100 disposal sites within the Bay Area was personally interviewed by the California Public Health group. Usually estimates were based on the characteristics of the collection vehicles, their routes, and the amounts in the fill that could be ascertained. The data were based upon the month-to-month average daily amounts deposited at the individual sites during the year preceding the survey, and were expressed in tons per day. Since the dates of each county's interviews varied, some noncomparability exists between the per day averages. When the actual amounts of wastes could not be obtained, close approximations were attempted by the Public Health Department interviewers with the use of a variety of methods. The methods included making a percentage estimate of the amounts of each category of wastes contained in each truckload, using as a basis information on known routes and known load categories, percentages obtained in other surveys, and of estimating percentages of wastes in the site, taking into consideration the average compaction ratio for the site.

Data on solid wastes received at the disposal sites were tabulated by the California Public Health Department under ten major types, viz., garbage and rubbish, bulky wastes, street refuse, food processing, industrial sewage solids, agricultural, demolition, ashes, dead animals, and special. Even though some indication was made as to type of wastes received, no quantitative estimates were made by type, and only the total wastes received at the sites were estimated.

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*The Health Department is collecting data from all the 58 counties in California as part of their 3-year study of the State as a whole.

The survey brought to light the interesting fact that a considerable amount of wastes does not find its way to the disposal sites. Consequently, the sum total received collectively at all of the sites represents only a fraction of the total quantity of wastes generated in the Bay Area. Using the solid wastes data as represented by the sum total received at the disposal sites, one could infer that the average daily per capita household wastes at the time the survey was made was around 5.3 pounds, varying from as low as 2 pounds to as high as 11 pounds. A detailed tabulation of comparable wastes figures, population, total and average per capita wastes is given in Table 2 for each of the 42 functional boundaries defined in this study.

A thorough analysis of functionally comparable factors relating to the wastes data in Table 2 proved to be practically impossible, because the amount of wastes received at the disposal sites in the Bay Area represents only about 35 to 40 percent of the total wastes generated in the area [2]. (The remainder, consisting of commercial, industrial, and agricultural wastes, is disposed of elsewhere.) Moreover, the wastes received at the sites are not strictly residential, inasmuch as some commercial, and possibly a slight amount of industrial, wastes (such as food processing) are included. Of prime importance is the fact that the wastes generated by the bulk of commercial, industrial, and agricultural sectors in the region were omitted from the tabulation (Table 2), inasmuch as the wastes were not transported to regular disposal sites. Efforts are currently being made by the Health Department to fill these deficiencies in the tabulation.

The incompleteness inherent in data based solely on wastes received at disposal sites made it necessary to develop methods for making estimates of the total wastes generated by various sources before the analyses required by the present study could be made.

Estimation of Solid Wastes Quantities from Sources of Wastes and Wastes Multipliers. Data on solid wastes can be classified in different ways, using different criteria for classification. Essentially, they can be classified by detailed sources, and by composition relating to a reference region which, in the present case, is a functional region (DSA). The major sources of solid wastes are the residential, commercial, public agencies, industrial, and agricultural sectors of the region. These could be classified in further detail from the point of view of studying the present rate of generation and future changes in quantities of wastes corresponding to changes in the sources. The composition of wastes can be classified according to the physical or chemical properties of wastes from the transfer and disposal point of view. Composition could be broken down as follows: bulky or light, combustible or noncombustible, organic or inorganic, dry or wet basis, and, finally, by proportions of the different items, e.g., paper, glass, wood, plastics, ferrous and nonferrous metals, etc. Judging from the existing literature, a delineation of the full gamut of cross-classifications of wastes relating to a particular region's wastes has not been made as yet. In the present study, the plan calls for the definition of the sources of wastes in the required detail, and for the estimation of the wastes quantities on an objective basis to describe the wastes generation in the functional regions. Other related information on composition is to be gathered and applied to the basic wastes data on a consistent and comparable manner in future research work. In this report, emphasis is placed on the detailed development of sources and wastes generation. During the third and subsequent years, possible future changes in quantities and in composition will be examined in detail while alternative transportation and disposal technologies will be considered for feasibility.

Sources of Wastes. The principal sources of wastes (residential, commercial, etc.) can be broken down further, depending upon the need, the nature of the wastes generation, and the composition characteristics. In this study, the sources identified for purposes of estimating the wastes generation by each functional boundary (DSA's) are listed in Table 3. A detailed definition of these sources is given in Appendix D.

TABLE 2

DETAILED TABULATION OF COMPARABLE WASTES FIGURES, POPULATION, TOTAL AND AVERAGE PER CAPITA WASTES

Disposal Service Area		Population	Solid Wastes		
Code	Name		tons/day	lb/day	lb/capita/day
01 01	Berkeley	117,870	145	290,000	2.46
02	Oakland	691,900	1,652	3,304,000	4.78
03	Alameda	69,200	375	750,000	10.84
04	Fremont	122,250	275	550,000	4.50
05	Pleasanton	25,300	30	60,000	2.37
06	East Alameda County	32,500	50	100,000	3.08
02 01	West Contra Costa	235,006	881	1,762,000	7.50
02	Central Contra Costa	280,530	432	864,000	3.08
03	East Contra Costa	60,340	215	430,000	7.13
03 01	West Marin	10,616	9.63	19,252	1.81
02	East Marin	127,051	190.37	380,748	3.00
04 00	Napa County	152,467	183	366,000	2.40
05 01	Richmond	90,540	Data Not Available		
02	Marina-Pacific Heights	67,100			
03	Central	93,295			
04	South of Market	28,260			
05	Western Addition	52,815			
06	Twin Peaks-Buena Vista	63,025			
07	South Van Ness	43,570			
08	Potrero-Bayshore	45,800			
09	Outer Mission	83,000			
10	So. Frway-Mt Davidson	58,075			
11	Lake Merced	29,620			
12	Sunset	92,400			
05 00	San Francisco	747,500	2,699	5,398,000	7.22
06 01	Daly City	65,000	89	178,000	2.74
02	South San Francisco	105,100	395	790,000	7.52
03	Pacifica	40,500	60	120,000	2.96
04	Central San Mateo	303,320	710	1,420,000	4.68
07 01	Palo Alto	68,593	175	350,000	5.10
02	Mountain View	51,178	170	340,000	6.64
03	Sunnyvale	84,703	256	512,000	6.04
04	Gilroy-Morgan Hill	24,201	36	72,000	2.98
05	Los Gatos	174,684	370	740,000	4.24
06	Los Altos	180,450	570	1,140,000	6.32
07	San Jose	344,775	1,005	2,010,000	5.83
08	Remainder of County	3,091			
08 01	Vacaville	29,491	78	156,000	5.29
02	Fairfield	65,104	127	254,000	3.90
09 01	Healdsburg	17,690	63	126,000	7.12
02	Santa Rosa	82,810	181	362,000	4.37
03	Western Sonoma	8,765	47	94,500	10.78
04	South Sonoma	78,375	140	280,000	3.57
TOTAL ALL DSA's		4,400,360	11,609	23,218,000	5.28

TABLE 3

LIST OF WASTES SOURCES

Source No.	Description of the Source of Wastes[a]
1.	Residential
1a	Single-Family Dwelling Units
1b	Multiple-Family Dwelling Units
2.	Restaurants and Hotels
3.	Institutions - Private (Schools and Colleges)
4.	Public Offices and Facilities
5.	Health Services (Private)
6.	Commercial and Service Establishments (Private)
7.	Construction and Demolition (Private and Public)
8.	Agriculture
8a	Orchards and Vineyards
8b	Vegetables, Berries, and Seed Crops
8c	Field Crops
8d	Milk Cows
8e	Feedlot Cattle
8f	Hogs and Pigs
8g	Hens and Pullets
8h	Turkeys
8i	Other Poultry
8j	Cut Flowers (Nursery)
8k	Dead Animals
9.	Extractive Industry (Mining)
10.	Canning and Preserving
11.	Other Food Processing
12.	Tobacco Industry
13.	Ordnance and Accessories
14.	Textiles and Apparel
15.	Lumber and Wood Products
16.	Furniture and Fixtures
17.	Paper and Allied
18.	Printing, Publishing, and Allied
19.	Chemicals and Allied
20.	Petroleum Refining
21.	Rubber and Plastic Products
22.	Leather and Allied
23.	Stone, Clay and Glass
24.	Primary Metals
25.	Fabricated Metal
26.	Nonelectrical Machinery
27.	Electrical Machinery
28.	Transportation Equipment
29.	Professional and Scientific Instruments
30.	Miscellaneous Manufacturing
31.	Nonclassifiable Establishments

[a] These sources are described in detail in Table 65 in Appendix E.

Solid Wastes Multipliers. Estimation of the amount of solid wastes generated by various sources of wastes (Table 3) for each of the 42 disposal service areas (functional boundaries defined in Appendix B) involved the following steps:

1. The wastes source units were measured either as number of units, or by level of activity represented either by employment or land use.
2. For each source of wastes, wastes multipliers were developed from available ongoing research studies. For example, results of solid wastes loading studies carried out in Santa Clara County, California, were utilized in developing the wastes multipliers.
3. Finally, the solid wastes generation was calculated as the product of the wastes multipliers and the level of source units developed in this section.

This approach had to be used because original and complete data on total amounts of solid wastes by functional boundaries could not be estimated for the study region by any other method.

Development of the wastes multipliers and wastes sources is discussed under the following categories: residential, commercial, nonmanufacturing and public agencies, industrial, and agricultural sources of wastes. The development of wastes multipliers for residential, commercial, nonmanufacturing and industrial sources of wastes was based on information collected through sample surveys conducted by the Food Machinery Corporation (FMC) in Santa Clara County (California) in 1967 and made available to this research team. In the case of agricultural sources of wastes, nearly all of the needed information was collected and analyzed by this research team. The detailed development of wastes multipliers is given below.

Residential Sources (Source Numbers 1a and 1b in Appendix D). Wastes multipliers were developed for single-family dwelling units and multiple-family dwelling units from a sample survey of households conducted by Food Machinery Corporation (FMC) in Santa Clara County. This sample included 359 single-family and 74 multiple-family dwelling units. The wastes data were considered reasonably complete and accurate. The average quantity of rubbish from single-family dwelling units was estimated at 2858 pounds (or 1.43 tons) per dwelling unit per year. This includes both the amount collected by regular collection agency and the amount hauled by the individual to the disposal site. For the multiple-family dwelling units, the average quantity was estimated at 1315 pounds (or 0.66 tons) per dwelling unit per year. It was assumed that the latter did not have any appreciable quantities hauled by the individuals to the disposal sites.

The number of single- and multiple-family dwelling units for 1966 was obtained from the Bay Area Simulation Study conducted by the Center for Real Estate and Urban Economics, University of California, for each of the 42 DSA's (Appendix B). The residential wastes figures were developed by multiplying the number of units and the corresponding multipliers. These are given in Table 4.

Commercial, Nonmanufacturing, and Public Agency Sources (Source Numbers 2 through 7 in Appendix D). These categories consist of a variety of sources, viz., shopping centers, hotels and restaurants, schools, hospitals, private and public offices, and other allied sources of wastes such as streets, parks, freeways, etc. The data on employment by these sources were developed on the basis of the data furnished by the California Department of Employment (Management Analysis Section) through the Association of Bay Area Governments. The original data on employment were available by Census tracts and SIC industry type. These have been aggregated to conform to the boundaries of the DSA's defined in this study (Appendix B). The data on employment by DSA for each of the nonmanufacturing sources, sources 2 through 7, are given in Table 5 along with industrial sources. The aggregation of employment data for the above categories as developed in this study do not strictly conform to

TABLE 4

RESIDENTIAL WASTES

Disposal Service Area		Housing Inventory		Wastes Generated (tons/yr)		
Code	Name	Single-Family Units 1	Multiple-Family Units 2	Single-Family Units 3	Multiple-Family Units 4	Total Wastes All Units 5
01 01	Berkeley	20,949	20,183	29,938	13,271	43,209
02	Oakland	154,393	72,598	220,643	47,737	268,380
03	Alameda	12,944	11,757	18,498	7,731	26,229
04	Fremont	21,760	3,772	31,097	2,480	33,577
05	Pleasanton	2,024	586	2,892	385	3,277
06	East Alameda County	5,838	663	8,343	436	8,779
02 01	West Contra Costa	57,719	13,526	82,486	8,894	91,380
02	Central Contra Costa	63,084	9,340	90,153	6,142	96,295
03	East Contra Costa	14,996	2,688	21,431	1,767	23,198
03 01	West Marin	3,636	189	5,196	124	5,320
02	East Marin	27,530	7,657	39,343	5,035	44,378
04 01	Napa County	40,190	8,200	57,436	5,392	62,828
05 01	Richmond	13,495	25,043	19,286	16,467	35,753
02	Marina-Pacific Heights	3,629	26,508	5,186	17,430	22,616
03	Central	2,034	55,954	2,907	36,793	39,700
04	South of Market	2,215	11,107	3,165	7,303	10,468
05	Western Addition	1,619	19,385	2,314	12,747	15,061
06	Twin Peaks-Buena Vista	7,541	18,451	10,777	12,132	22,909
07	South Van Ness	2,217	12,472	3,168	8,201	11,369
08	Potrero-Bayshore	5,623	4,804	8,036	3,159	11,195
09	Outer Mission	17,973	8,507	25,685	5,594	31,279
10	So. Frway-Mt. Davidson	14,543	5,689	20,783	3,741	24,524
11	Lake Merced	7,822	2,635	11,178	1,733	12,911
12	Sunset	27,328	7,160	39,054	4,708	43,762
06 01	Daly City	15,675	3,583	22,401	2,356	24,757
02	South San Francisco	25,684	4,689	36,705	3,083	39,788
03	Pacifica	8,738	1,311	12,487	862	13,349
04	Central San Mateo	76,172	23,492	108,857	15,447	124,304
07 01	Palo Alto	16,600	4,424	23,723	2,909	26,632
02	Mountain View	10,438	4,446	14,917	2,923	17,840
03	Sunnyvale	19,354	6,278	27,659	4,128	31,787
04	Gilroy-Morgan Hill	6,002	365	8,577	240	8,817
05	Los Gatos	38,192	8,459	54,580	5,562	60,142
06	Los Altos	42,461	6,787	60,681	4,463	65,144
07	San Jose	73,259	19,147	104,694	12,590	117,284
08	Remainder of County	782	38	1,118	25	1,143
08 01	Vacaville	7,768	595	11,101	391	11,492
02	Fairfield	11,881	5,567	16,979	3,661	20,640
09 01	Healdsburg	7,401	742	10,577	488	11,065
02	Santa Rosa	24,320	3,580	34,756	2,354	37,110
03	Western Sonoma	2,796	280	3,996	184	4,180
04	South Sonoma	24,008	2,410	34,310	1,585	35,895
TOTAL		942,633	445,067	1,347,113	292,653	1,639,766

NOTE: Columns 1 and 2: Bay Area Simulation Study (BASS), University of California, Center for Real Estate and Urban Economics

Column 3: Column 1 multiplied by 1.42910 (see text)

Column 4: Column 2 multiplied by 0.65755 (see text)

Column 5: Column 3 plus Column 4

TABLE 5

EMPLOYMENT BY DSA AND BY WASTES SOURCE[a]

DSA 1	Restaurants and Hotels 2	Institutions Private (Schools and Colleges) 3	Public Offices and Facilities 4	Health Services (Private) 5	Commercial and Service Establishments (Private) 6	Construction and Demolition (Public and Private) 7	Agriculture 8	Extractive Industry 9	Canning and Preserving 10
01 01	2,243	405	23,656	2,345	15,405	2,044	152	0	420
02	9,573	2,156	33,744	10,789	127,192	13,259	1,301	873	5,279
03	562	150	14,058	730	4,735	1,442	123	0	81
04	527	69	3,410	272	6,730	4,569	2,516	145	207
05	78	0	687	30	892	1,897	519	232	6
06	184	32	6,821	335	2,102	1,268	1,109	0	10
02 01	2,308	361	7,174	1,537	24,100	4,276	194	174	196
02	2,416	507	11,555	2,617	21,677	8,822	1,602	131	135
03	556	54	1,996	357	4,983	669	3,812	30	288
03 01	45	0	196	16	150	126	169	0	0
02	1,637	840	6,234	1,913	16,738	3,104	1,029	80	0
04 01	1,741	1,222	17,708	1,851	14,190	1,872	3,731	0	0
05 01	1,037	1,269	10,461	4,549	9,641	1,541	66	0	55
02	1,469	632	7,934	3,325	9,123	4,520	10	1	14
03	20,407	567	14,794	4,092	108,121	10,382	416	240	609
04	3,324	193	14,315	194	66,962	1,268	13	80	1,203
05	464	137	2,634	1,580	6,611	1,005	18	0	138
06	213	93	1,770	584	2,701	1,027	14	0	2
07	1,270	468	3,374	707	19,688	689	13	1	831
08	327	43	9,734	13	11,173	357	87	0	708
09	452	261	1,119	1,126	4,802	309	34	4	153
10	222	284	2,043	49	3,450	1,135	54	0	0
11	241	119	3,153	274	4,189	120	4	0	10
12	490	278	1,874	365	6,886	104	41	0	1
06 01	504	81	1,302	271	5,593	1,887	145	0	0
02	1,721	183	4,708	679	31,619	2,865	91	0	182
03	191	8	861	61	1,193	1,223	47	41	0
04	5,153	795	13,235	4,128	48,044	8,528	2,499	4	140
07 01	1,358	9,095	3,378	3,379	19,062	3,382	274	29	325
02	713	151	1,835	297	8,731	1,819	165	0	90
03	1,350	26	5,813	341	10,056	2,831	442	0	874
04	319	21	630	290	2,033	391	2,009	0	688
05	1,526	172	4,004	1,432	10,563	3,981	1,417	28	565
06	1,744	798	4,750	1,610	13,288	3,257	1,468	30	1,107
07	4,608	685	18,150	4,053	46,566	6,418	2,896	38	7,720
08	22	0	125	0	1,147	0	4,726	14	20
08 01	726	6	1,312	51	2,776	549	1,982	80	0
02	782	151	4,988	828	6,090	955	2,300	91	0
09 01	395	39	778	234	4,038	410	1,586	33	358
02	459	39	744	36	1,504	390	1,522	35	34
03	179	41	258	176	1,085	164	1,390	99	30
04	1,755	226	3,986	1,779	14,691	3,095	829	11	330
TOTAL	75,321	22,647	271,301	59,295	720,320	107,950	42,815	2,524	22,809

[a] Employment data in this table were tabulated directly from those furnished by the California Department of Employment. The original data were by Census tracts and by SIC codes. These have been reaggregated to correspond to the DSA boundaries and wastes sources defined in this study. (The column numbers correspond to the wastes sources defined in Table 3. See text.)

TABLE 5 (Continued)

DSA	Other Food Processing 11	Tobacco Industry 12	Ordnance and Accessories 13	Textiles and Apparel 14	Lumber and Products 15	Furniture and Fixtures 16	Paper and Allied Products 17	Printing, Publishing and Allied 18	Chemicals and Allied 19	Petroleum Refining 20	Rubber and Plastic Products 21
01 01	1,044	0	0	2	32	207	411	580	2,077	14	134
02	13,140	0	0	1,147	878	1,168	2,696	4,230	1,926	1,648	827
03	202	0	0	0	156	22	187	68	575	0	11
04	515	0	0	33	9	279	661	137	704	30	0
05	14	0	0	0	0	44	0	0	0	0	0
06	26	0	0	153	0	0	0	56	0	0	0
02 01	979	0	0	52	57	185	47	510	1,709	4,120	47
02	678	0	17	4	17	24	3	473	970	1,741	10
03	1,440	0	0	0	36	0	2,815	112	1,093	0	287
03 01	0	0	0	0	0	0	0	0	0	0	0
02	322	0	0	14	156	26	17	320	0	0	55
04 01	1,146	0	0	486	10	32	28	339	15	0	12
05 01	162	0	0	36	0	1	0	12	2	0	0
02	42	0	0	13	5	6	0	67	3	0	0
03	1,795	0	0	2,500	12	836	295	4,379	770	2,623	1
04	3,547	5	0	2,759	51	346	797	6,698	726	750	113
05	406	0	0	139	0	77	0	427	3	0	0
06	4	0	0	0	0	0	0	33	0	0	0
07	2,449	21	0	1,780	44	405	223	842	121	38	44
08	2,088	0	0	543	128	568	54	117	139	0	50
09	452	0	0	89	0	33	0	9	23	0	0
10	2	0	0	7	0	0	0	3	5	0	3
11	28	0	0	0	0	0	0	2	0	0	0
12	2	1	6	8	1	20	0	16	0	0	0
06 01	0	0	0	13	4	0	0	34	0	0	0
02	1,754	0	0	235	63	300	498	709	1,089	33	113
03	0	0	0	4	0	0	0	28	0	0	0
04	1,355	0	33	137	274	436	123	1,543	858	264	243
07 01	157	0	1,559	1	32	0	146	568	67	1	0
02	43	0	1,424	1	111	69	0	225	30	35	3
03	423	0	16,029	0	0	9	30	267	145	0	7
04	333	0	0	0	1	40	33	34	72	0	2
05	274	0	0	95	23	40	268	140	10	0	7
06	537	0	0	25	257	346	638	403	188	0	30
07	3,741	0	3,779	568	182	117	500	1,641	686	97	444
08	9	0	0	0	0	0	0	0	0	0	0
08 01	1,329	0	0	0	0	0	0	32	0	0	0
02	1,920	0	0	0	23	0	0	58	0	0	0
09 01	393	0	0	57	689	2	0	162	3	0	0
02	58	0	0	0	307	4	0	4	0	0	0
03	34	0	0	0	636	28	0	26	27	0	7
04	363	0	0	40	196	43	0	104	8	0	0
TOTAL	43,186	27	22,847	10,941	4,390	5,722	10,470	25,408	14,044	11,394	2,450

TABLE 5 (Continued)

DSA	Leather and Allied 22	Stone, Clay, and Glass 23	Primary Metals 24	Fabricated Metals 25	Nonelectrical Machinery 26	Electrical Machinery 27	Transportation Equipment 28	Professional and Scientific Instruments 29	Miscellaneous Manufacturing 30	Nonclassifiable Establishments 31	Total Employment
01 01	85	74	564	1,069	872	226	201	284	65	50	54,661
02	101	3,445	3,576	7,538	8,029	2,259	2,236	521	465	173	260,169
03	0	0	0	750	84	0	1,367	1	47	0	25,351
04	0	325	1,247	492	19	159	6,242	0	29	4	29,330
05	0	149	0	0	0	0	0	0	5	0	4,553
06	0	0	0	135	6	0	0	3	7	1	12,248
02 01	192	673	224	1,814	467	255	605	849	134	39	53,278
02	0	353	517	26	580	76	93	289	16	52	55,401
03	0	554	3,195	345	30	0	62	0	28	2	22,744
03 01	0	0	0	0	0	5	0	0	0	0	707
02	0	203	125	53	16	700	146	0	61	87	33,876
04 01	132	77	632	82	74	13	10	28	11	26	45,468
05 01	0	43	0	2	4	3	0	0	0	12	28,896
02	0	7	0	0	0	0	15	0	30	21	27,237
03	1	373	844	373	330	53	84	55	276	153	175,381
04	95	94	187	2,438	1,233	603	2,306	145	446	25	110,906
05	0	0	0	2	10	6	1	14	10	6	13,688
06	0	0	0	0	2	0	0	0	2	3	6,448
07	5	355	193	483	827	137	196	27	207	23	35,461
08	184	130	289	3,002	505	254	404	0	185	6	31,088
09	0	2	0	114	0	14	0	0	22	3	9,021
10	0	0	0	136	7	0	0	0	6	3	7,409
11	0	0	0	0	0	0	0	0	28	3	8,171
12	1	0	0	16	0	3	0	1	15	5	10,134
06 01	0	45	0	17	0	0	1	0	15	9	9,921
02	83	207	1,464	1,607	547	617	117	38	143	19	51,693
03	0	0	0	0	0	1	0	0	0	2	3,660
04	2	521	269	1,067	1,675	9,329	523	263	221	88	101,750
07 01	0	18	10	25	84	8,399	1,070	719	1	168	53,307
02	0	13	0	51	558	5,808	26	137	0	36	22,371
03	0	36	0	186	239	4,016	79	263	2	14	43,508
04	3	39	0	18	117	0	84	0	0	3	7,160
05	0	3	4	31	141	168	3	67	5	21	24,988
06	0	1,745	474	811	346	690	91	66	104	21	34,826
07	0	776	284	1,382	5,089	2,658	2,236	52	394	119	115,879
08	0	0	0	0	0	0	0	0	0	0	6,063
08 01	0	37	0	4	0	0	0	0	0	0	8,884
02	0	44	0	325	118	0	51	23	1	30	18,778
09 01	0	0	8	146	57	2	0	0	43	0	9,433
02	0	0	7	30	4	0	0	0	48	39	5,244
03	0	0	0	0	6	0	18	0	0	0	4,204
04	159	86	24	108	138	39	28	152	10	33	28,231
TOTAL	1,043	10,427	14,137	24,678	22,214	36,493	18,295	3,997	3,082	1,299	1,611,526

the sources for which data on wastes generation were developed by the FMC in its Santa Clara County study. Only an average multiplier could be arrived at in a number of these sources. The average multipliers were derived by dividing the total wastes by corresponding employment in Santa Clara County. The multiplier was estimated as 7620 pounds per employee per year, and was applied to sources 2, 3, 4, 5, and 6 in Appendix D. A separate multiplier was developed for demolition and construction (source 7) from the total wastes generated and the corresponding employment in that industry in Santa Clara County. The multiplier was estimated to be 82,504 pounds or 41.25 tons per employee and is applied for source 7 (in Appendix D). This figure is considered somewhat high and will probably have to be revised downward when the data from the State's studies become available. Detailed calculations pertaining to this category are given in Table 6.

TABLE 6

MULTIPLIERS FOR NONMANUFACTURING INDUSTRY,
COMMERCIAL AND PUBLIC FACILITIES

Waste Source	Annual[a] Wastes, Volume cu yd 1	Employment[b] 2	Annual[c] Wastes, Volume per Employee cu yd 3	Annual[a] Wastes, 1000 lb 4	Annual[d] Wastes, lb per Employee 5	Annual[e] Wastes, ton per Employee 6
Commercial[f] and Public Facilities	3,946,928	184,153	21.433	1,403,287.1	7,620.22	3.81011
Demolition and Construction	2,115,717	22,079	95.824	1,821,607.7	82,504.08	41.25205

[a] Columns 1 and 4: Food Machinery Corporation (FMC) Santa Clara Study, 1967, unpublished data

[b] Column 2: Tabulation of data obtained from California Department of Employment, San Francisco Office, Research and Statistics

[c] Column 3: Column 1/Column 2

[d] Column 5: Column 4/Column 2

[e] Column 6: Column 5/2000

[f] This group includes all wholesale and retail trade, transportation, utilities and other services, churches, shopping centers, and all publicly-owned facilities

Industrial Sources (Sources 10 through 31 in Appendix D). A survey of representative industrial firms was carried out by FMC in Santa Clara County for developing the industrial wastes multipliers. A distinction was made between firms (enterprises) and establishments representing actual location of economic activity. The Food Machinery Corporation developed wastes multipliers per establishment which were based on the wastes generated by establishments and the ratio between firms to establishments. Consequently, the wastes multipliers developed by FMC relate only to the number of establishments, and no consideration is given to the size of the establishments.

On the basis of experience gained in the study reported herein, it became evident that to arrive at meaningful multipliers, size as well as number of establishments must be taken into consideration. Another possible approach would be the use of actual production of goods as a factor. However, since employment was the only variable on which data could be obtained in sufficient detail in the nine-county Bay Area, it was used as the proxy variable representing the size of a given industry. Original survey data on wastes collected by FMC from the various industries, and generously made available to the Planning and Economics team, were used to develop multipliers by large and small firms, and by type of industry (Standard Industrial Classification – SIC Code). The method is briefly described in the two following paragraphs.

Data obtained from the FMC survey represented information gained from 32 of the 36 large firms (100 or more employees per firm) interviewed by the organization. (The total number of large firms located in Santa Clara was 102.) The information consisted of detailed data on wastes generation, seasonality, etc. These data were then used in conjunction with comparable data on employment of the firms sampled to develop solid wastes multipliers by industry type. The total wastes generation by the canning and preserving industry (SIC 20) was ascertained by FMC by way of personal interviews. These data were divided by corresponding total employment in the industry to arrive at the appropriate wastes multiplier. The multipliers are developed by SIC industry type (19 through 39). The calculations and multipliers are presented in Table 65, Appendix E.

The following comments concerning the lack of certain industry data in the survey are in order: multipliers for the canning and preserving (SIC 203), textile (SIC 22), chemical and allied (SIC 28), petroleum (SIC 29), primary metal (SIC 33), and instrument (SIC 38) industries were not available from the survey data. The extractive industry (mostly mining) were excluded, since usable information was not available. Petroleum refining (SIC 29) was not considered, inasmuch as the wastes from this industry is mostly treated as liquid wastes, and its overall effect on solid wastes generation is not appreciable (at least in the Bay Area). With regard to the majority of the other SIC groups for which data were lacking, some may be considered as not being important in terms of the Bay Area as a whole.

Only a fraction of the 1222 small industrial firms (less than 100 employees per firm) surveyed by FMC returned the questionnaire. These responses were made available by the corporation to the research team. Of the responses, nearly 122 questionnaires contained information which could be used in developing wastes multipliers. The data were tabulated by the research team in terms of average weekly wastes output per small firm by SIC group. A separate tabulation of employment of small firms by SIC group was made with the intention of determining the average size of employment comparable to the average weekly wastes. These were used to develop wastes multipliers for small industrial firms, as is indicated in Table 66, Appendix E.

The multipliers developed for large and small industrial firms were used to develop average multipliers for the industry as a whole. For each of the SIC groups, the multipliers for the large and small firms were weighted by the corresponding total employment in the county to arrive at an average. These multipliers were expressed in cubic yards per employee, and were converted to pounds and tons per employee, using densities of wastes developed by FMC (unpublished data). The various stages of these calculations are given in Table 7. Data on employment by industrial wastes sources (cf. Table 5) were tabulated from the data furnished by the California Department of Employment and made available to this study by the Association of Bay Area Governments.

TABLE 7

INDUSTRIAL MULTIPLIERS

Standard Industrial Classification		Small Firms		Large Firms		Annual Waste: All Firms			
No.	Title	Total[a] Employment 1	Annual Waste[b] Volume per Employee (cu yd) 2	Total[a] Employment 3	Annual Waste[c] Volume per Employee (cu yd) 4	Volume per[d] Employee (cu yd) 5	Densities[e] lb/cu yd 6	Pounds per[f] Employee 7	Tons per[g] Employee 8
19	Ordnance and Accessories	h	h	29,499	4.476	4.476	294.4	1,317.7	0.65885
203	Canning and Preserving	-	-	-	8.977	8.977	1,240.0	11,131.4	5.5657
20	Other Food Processing (Except 203)	920	20.961	4,306	8.720	10.875	885.8	9,633.1	4.81655
21	Tobacco	-	-	-	-	-	-	-	2.49365[i]
22	Textiles	-	-	-	-	-	-	-	0.52575[j]
23	Apparel	98	35.360	623	2.077	6.601	159.3	1,051.5	0.52575
24	Lumber and Wood Products	455	48.492	217		48.492	894.5	43,376.1	21.68805
25	Furniture and Fixtures	385	86.877			86.877	464.0	40,310.9	20.15545
26	Paper and Allied Products	570	65.442	1,535	37.440	45.022	557.0	25,077.3	12.53865
27	Printing, Publishing, and Allied	1,744	25.230	1,923	7.252	15.802	1,671.0	26,405.1	13.20255
28	Chemicals and Allied	701	18.348	937		18.348	895.0	16,421.1	8.21075
29	Petroleum Refining	k	k	k	k	k	k	k	k
30	Rubber and Plastics	173	28.583	653	18.854	20.892	148.2	3,096.2	1.54810
31	Leather	-	-	-	-	-	-	-	2.49365[i]
32	Stone, Clay, Glass, and Concrete	960	29.235	1,696	5.260	13.926	2,601.5	36,228.5	18.11425
33	Primary Metals	h	4.443	-	-	-	-	-	6.7300 [l]
34	Fabricated Metal Products	1,259	21.214	1,304	13.206	17.140	785.3	13,460.0	6.7300
35	Nonelectrical Machinery	2,838	17.909	9,805	11.401	12.862	650.3	8,364.2	4.18210
36	Electrical Machinery	2,337	16.645	37,814	7.333	7.875	756.5	5,957.4	2.97870
37	Transportation Equipment	557	14.348	4,183	24.580	23.378	290.3	6,786.6	3.39330
38	Instruments	825	8.943	926	NA	8.943	562.9	5,034.0	2.51700
39	Miscellaneous Manufacturing Industries	317	5.946	149	NA	10.493	475.3	4,987.3	2.49365[i]

[a] Columns 1 and 3 - Tabulated from data obtained from California Department of Employment, (Research and Statistics), San Francisco office

[b] Column 2 - From Column 4 of Table 66 (Appendix E)

[c] Column 4 - From Column 3 of Table 65 (Appendix E)

[d] Column 5 - The average multiplier (cu yd/employee) for the industry as a whole was obtained for each SIC as the weighted average of small and large firm multipliers (Columns 2 and 4), using employment (Columns 1 and 3) as weights

[e] Column 6 - Unpublished data furnished by FMC Santa Clara study, 1967

[f] Column 7 - Column 5 multiplied by Column 6

[g] Column 8 - Column 7 divided by 2,000

[h] Data not available

[i] The multiplier for the SIC 39, Miscellaneous Manufacturing Industries, calculated as weighted average of all industry multipliers available. This multiplier is used wherever an industry had no data available, e.g., Tobacco (SIC 21), Leather (SIC 31).

[j] Same as the multiplier for Apparel (SIC 23)

[k] Omitted from calculations

[l] Same as the multiplier for Fabricated Metals (SIC 34)

Agricultural Sources (Source Number 8 – 8a through 8k). As shown in Table 3, the agricultural sources were classified as follows:

8a	Orchards and vineyards
8b	Vegetables, berries and seed crops
8c	Field crops
8d	Milk cows
8e	Feedlot cattle
8f	Hogs and pigs
8g	Hens and pullets
8h	Turkeys
8i	Other poultry
8j	Cut flowers (nursery)
8k	Dead animals

Source units for orchards, vineyards, vegetables, seed crops, field crops, and cut flowers (8a, b, c, and j) generally were measured by acres, and the wastes by pounds or tons per acre. The acreage data were obtained from the County Agricultural Commissioner's Report for 1966, and the wastes multipliers were obtained from a variety of sources. Wastes generation was calculated for each crop in the group before group totals were formed, since each crop has a different wastes production rate. Source units for milk cows, feedlot cattle, hogs and pigs, hens and pullets (Sources 8d, e, [illegible] and g) were measured by number of animals inventoried for the year 1966. These w[illegible]ined from the County Agricultural Commissioner's Report. The wastes multi[illegible]nure expressed as pounds per number of animals) were obtained from available pu[illegible]shed sources. The source units were multiplied by the wastes multipliers to obtain the total wastes generated. In the case of turkeys and other poultry (Sources 8h and i), the source units were number of heads produced during the year. The data were obtained from the Agricultural Commissioner's Report. The wastes multipliers (expressed as pounds per unit hatched) were obtained from available published sources. With respect to dead animals (Source 8k), the wastes were developed separately for cattle, sheep, hogs, and pigs, and poultry on the basis of the source units, mortality rate, and average weight – utilizing in each case separate multipliers and the corresponding units (inventories or production during the year).

The data used in estimating total agricultural wastes were obtained from a number of sources. Among them were consultation with the appropriate agricultural agent, with members of the University's Agricultural Extension at Berkeley and with those of its agricultural engineering department at Davis, and, finally, the literature on the subject. The judgment factor entered into these estimates to a greater degree than in those of the other sources of wastes already discussed.

The wastes multipliers for orchards and vineyards were estimated for each fruit and nut crop separately as pounds per acre-year by bearing and nonbearing type. The multipliers were developed in two stages. In the first stage, data on per-tree wastes generation were obtained from FMC data [3] separately for bearing and nonbearing types of trees. (These data include pruning and attrition wastes, if any.) Values for per-tree output were multiplied by those for the number of trees per acre [4,5], to arrive at a value for the amount of wastes generated per acre by each type of fruit or nut crop. The multipliers are given in Table 8.

The average of each of the wastes multipliers for vegetable, berry, and nut crops (8b) was used in arriving at wastes generation for this source group. The mushroom crop was treated separately, since its wastes generation is out of scale with that of the other crops in this group, due to the need of disposing of large amounts of bedding (straw and manure). The multiplier for vegetables, berries, and seed crops was estimated at 3.0 tons per acre per year [2]; and that for mushrooms, 218 tons per acre per year. The latter is based upon a multiplier of 10 pounds per square foot [3].

TABLE 8

MULTIPLIERS FOR VINEYARDS AND ORCHARDS

Source of Wastes (Tree or Vine)	Multiplier (lb/acre-yr)	
	Bearing	Nonbearing
Apple	3,100	250
Apricot	3,084	750
Cherry	2,853	625
Peach	2,934	720
Pear	6,084	1,620
Plum	4,080	760
Prune	1,083	592
Olive	3,118	-
Fig	3,117	-
Persimmon	3,117	-
Orange	3,117	-
Walnut	1,010	255
Almond	642	-
Miscellaneous Fruits and Nuts	3,117	753
Grape	3,224	1,209

Generally, in planning for the disposal of agricultural wastes, those generated in the production of vegetables, berries, and seeds are not taken into consideration, since generally they are not regarded as subject to public disposal. Inasmuch as the study reported herein is concerned with all aspects of wastes management, these wastes had to be taken into consideration.

In arriving at an estimate of total wastes generated in the production of field crops (8c), an average multiplier of 1.5 tons per acre per year [2] was used. Field crops generally are not considered as significant wastes generators, since they either are disc plowed into the soil or burned in the field.

With respect to milk cows, feedlot cattle, and hogs and pigs, land used for range and pasture accounts for approximately three-quarters of the total acreage devoted to agriculture in the nine Bay Area counties. Generally, wastes generated on this land do not present a disposal problem, at least not for the present.

To estimate the total manure produced by milk cows and feedlot cattle, the number of cattle (inventory) was multiplied by the average wastes multiplier, 13.21 tons per head per year [6]. The wastes multiplier used in arriving at a value for pig and hog manure production was 1.28 tons per pig per year [6].

The multipliers used in arriving at total wastes production for hens and pullets (number from inventory) was 67.5 tons per 1000 head per year [7]; for turkeys (annual turkey production) 90 pounds per head per hatch-to-slaughter; and for other poultry (miscellaneous poultry and rabbits) 9 pounds per head-to-slaughter [7].

Wastes generated in cut flower production have become a disposal problem, since they no longer can be burned on site. The multiplier used in arriving at wastes production from this source was 25 tons per acre per year [8].

Tonnage of dead animals was arrived at on the basis of one-half the average weight of each class of animal (many of them die before reaching full growth) and a mortality factor. Farm animal mortality was estimated to be at the rate of 0.5 percent per month for large animals, and 1.0 percent for poultry [9]. The multiplier used for cattle, hogs, and pigs was 0.06 times one-half the average weight per animal; for hens and pullets, 0.12 times one-half the average weight; miscellaneous poultry, 0.03 times one-half the average weight; and for sheep, 0.06 times one-half the average weight.

The various source units and data on acreage, and number of heads (inventoried and produced) pertinent to the year 1966 are listed in Table 9. Values for total wastes generated by each of the sources, 8a through 8k, are presented in Table 10.

Total Wastes Generated Within the Region

The amounts of solid wastes generated within each functional boundary were estimated by multiplying the source units and the corresponding wastes multipliers with respect to each of the wastes sources listed in Table 3. Final and immediately preceding calculations for wastes generation by residential sources are given in Table 4; by commercial nonmanufacturing, public agencies and by industrial sources, in Table 11; and by agricultural sources, in Table 10.

Employment

Data on employment were available at the highest level of detail as compared to those for other variables evaluated in this investigation. The primary data used in the calculations were those tabulated by the California Department of Employment according to Census tract, and by detailed categories of enterprises commonly known as the Standard Industrial Classification code (at the four-digit level). Problems involved in the use of the data had to do with time period, coverage, and uniformity. The basic employment data were aggregated to conform to the definitions of wastes sources as defined in Table 3 and to correspond to the Census tract boundaries defined for each of the functional boundaries (DSA's in Appendix C). Final tabulations of the available data on employment are given in Table 5.

The aggregated data and the wastes multipliers developed in this study were then used in developing complete and comparable data on solid wastes generation by commercial and industrial sources in the study regions.

Population

The plan for the evaluation of the variable "population" involved the estimation of data on population on a comparable basis and as accurately as possible for the 42 functional regions defined in the present study. The Census tract was used as the primary source unit, and aggregations of Census tracts (or portions thereof) were made to correspond to DSA boundaries. The calendar year 1966 was made the reference period for the population data so as to have them correspond to the other data elements in the study. The population tabulation is given in Table 12.

In making the tabulation, the problems relating to reliability and accuracy could not be completely and satisfactorily resolved. Santa Clara County, in which a special census was taken in April of 1966, was the only county in which an official count was made since the 1960 census. Methods of estimation varied in the other counties. Sources of population data, methods (where known) of estimating population numbers, the dates of the estimations, limitations of the data, and adjustments made by the research team are described in Appendix F.

TABLE 9

AGRICULTURE SOURCE UNITS BY DSA[a]: 1966

Disposal Service Area		Orchards and Vineyards (acres)	Vegetables, Berries and Seed Crops (acres)	Field Crops (acres)	Milk Cows (Head)	Feedlot Cattle (head)	Hogs and Pigs (head)	Hens and Pullets (head)	Turkeys (head)	Other Poultry (head)	Cut Flowers (acres)	Dead Animals (head)
Code	Name											
01 01	Berkeley	0	0	0	0	0	0	0	0	0	0	0
02	Oakland	363	3,614	0	0	277	0	0	0	0	125	33,851
03	Alameda	0	0	0	0	0	0	0	0	0	0	0
04	Fremont	1,948	3,724	2,946	637	648	5,295	52,230	0	2,607,380	53	194,645
05	Pleasanton	1,152	1,862	3,172	1,238	0	883	156,690	0	7,822,140	0	177,720
06	East Alameda County	1,584	1,753	16,540	0	0	2,647	52,230	0	2,607,380	0	16,926
02 01	West Contra Costa	0	0	0	0	0	0	0	0	0	54	0
02	Central Contra Costa	2,138	369	3,738	0	0	590	3,015	0	650	0	416
03	East Contra Costa	18,957	12,073	33,637	3,750	25,000	5,310	27,136	0	5,850	0	5,475
03 01	West Marin	0	16	2,800	20,970	3,735	270	23,140	0	0	19	4,275
02	East Marin	55	4	700	2,330	415	30	12,460	0	0	24	1,661
04 01	Napa County	19,142	0	8,709	1,185	1,325	0	296,911	127,959	679,645	0	60,008
05 01	Richmond											
02	Marina-Pacific Heights											
03	Central											
04	South of Market											
05	Western Addition											
06	Twin Peaks-Buena Vista											
07	South Van Ness											
08	Potrero-Bayshore											
09	Outer Mission											
10	So. Frwy-Mt. Davidson											
11	Lake Merced											
12	Sunset											
06 01	Daly City	0	530	0	0	0	3,548	0	0	0	9	213
02	South San Francisco	0	0	0	0	0	0	0	0	0	14	0
03	Pacifica	0	0	0	220	0	0	0	0	0	5	13
04	Central San Mateo	56	3,005	8,010	880	0	187	1,425	0	0	70	235
07 01	Palo Alto	0	0	0	0	0	0	0	0	0	322	0
02	Mountain View	0	0	0	0	0	0	0	0	0	322	0
03	Sunnyvale	0	0	0	545	0	0	0	0	0	323	33
04	Gilroy-Morgan Hill	16,288	5,858	5,889	4,905	5,377	115	706,800	0	16,240	0	85,936
05	Los Gatos	10,208	1,674	1,682	0	0	0	0	0	0	0	0
06	Los Altos	4,138	837	841	0	0	0	0	0	0	0	0
07	San Jose	3,388	837	841	4,905	0	1,035	0	0	0	107	356
08	Remainder of County	20,324	7,531	7,572	545	0	0	176,700	0	4,060	0	21,359
08 01	Vacaville	9,527	8,699	92,880	0	0	67	173,250	80,280	902,838	0	50,287
02	Fairfield	6,780	5,799	19,737	2,765	15,675	1,283	19,250	8,920	100,315	0	6,770
09 01	Healdsburg	27,803	144	0	5,305	1,000	290	0	0	0	0	396
02	Santa Rosa	2,391	143	0	5,305	1,000	1,160	696,200	222,400	6,436,840	0	283,769
03	Western Sonoma	2,169	48	0	21,220	4,000	290	0	0	0	0	1,531
04	South Sonoma	7,071	144	36,760	21,220	4,000	1,160	1,044,300	333,600	9,655,260	0	426,565
	NINE-COUNTY TOTAL	135,082	58,664	246,454	97,925	62,452	24,160	3,441,737	773,159	30,838,998	1,447	1,372,440

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[a] Data tabulated directly from the original sources. (See text.)

TABLE 10

AGRICULTURAL WASTES BY DSA, BY SOURCE[a]: 1966
(tons per year)

Disposal Service Area		Orchards and Vineyards 8a	Vegetables, Berries, Seed Crops 8b	Field Crops 8c	Milk Cows 8d	Feedlot Cattle 8e	Hogs and Pigs 8f	Hens and Pullets 8g	Turkeys 8h	Other Poultry 8i	Cut Flowers (Nursery) 8j	Dead Animals 8k	Total Agricultural Wastes 8
Code	Name												
01 01	Berkeley	0	0	0	0	0	0	0	0	0	0	0	0
02	Oakland	554	10,843	0	0	3,667	0	0	0	0	3,115	58	18,237
03	Alameda	0	0	0	0	0	0	0	0	0	0	0	0
04	Fremont	1,706	11,172	4,418	8,423	8,555	6,765	3,526	0	6,556	1,335	334	52,790
05	Pleasanton	1,139	5,586	4,758	16,351	0	1,127	10,577	0	19,669	0	305	59,512
06	East Alameda County	2,176	5,258	24,811	0	0	3,382	3,525	0	6,556	0	29	45,737
02 01	West Contra Costa	0	0	0	0	0	0	0	0	0	1,340	0	1,340
02	Central Contra Costa	1,287	1,108	5,606	0	0	754	204	0	3	0	21	8,983
03	East Contra Costa	15,284	36,218	50,457	49,549	330,325	6,783	1,831	0	26	0	1,026	491,499
03 01	West Marin	0	48	4,200	277,077	49,351	345	1,562	0	0	465	564	333,612
02	East Marin	86	12	1,050	30,786	5,483	38	841	0	0	620	100	39,016
04 01	Napa County	25,491	0	11,322	15,657	17,507	0	20,041	5,758	3,058	0	157	98,991
05 01	Richmond												
02	Marina-Pacific Heights												
03	Central												
04	South of Market												
05	Western Addition												
06	Twin Peaks-Buena Vista												
07	South Van Ness												
08	Potrero-Bayshore												
09	Outer Mission												
10	So. Frwy-Mt. Davidson												
11	Lake Merced												
12	Sunset												
06 01	Daly City	0	1,591	0	0	0	4,532	0	0	0	245	66	6,434
02	South San Francisco	0	0	0	0	0	0	0	0	0	367	0	367
03	Pacifica	0	0	0	2,907	0	0	0	0	0	123	19	3,049
04	Central San Mateo	66	9,014	12[illegible]	11,627	0	239	96	0	0	1,715	80	34,852
07 01	Palo Alto	0	0	0	0	0	0	0	0	0	8,055	0	8,055
02	Mountain View	0	0	0	0	0	0	0	0	0	8,055	0	8,055
03	Sunnyvale	0	0	0	7,201	0	0	0	0	0	8,055	15	15,271
04	Gilroy-Morgan Hill	18,684	17,574	8,833	64,810	71,046	147	47,709	0	73	0	479	229,355
05	Los Gatos	11,429	5,021	2,524	0	0	0	0	0	0	0	0	18,974
06	Los Altos	4,637	2,510	1,262	0	0	0	0	0	0	0	0	8,409
07	San Jose	3,941	2,511	1,262	64,810	0	1,322	0	0	0	2,685	220	76,751
08	Remainder of County	23,653	22,595	11,356	7,201	0	0	11,927	0	18	0	46	76,796
08 01	Vacaville	12,554	26,096	141,061	0	0	86	11,695	3,613	4,063	0	20	199,188
02	Fairfield	9,061	17,398	29,606	36,535	207,113	1,639	1,299	401	451	0	970	304,473
09 01	Healdsburg	34,890	431	0	70,095	13,213	371	0	0	0	0	217	119,217
02	Santa Rosa	3,188	431	0	70,095	13,213	1,482	46,994	10,008	16,116	0	217	161,744
03	Western Sonoma	3,359	144	0	280,380	52,852	370	0	0	0	0	868	337,973
04	South Sonoma	10,989	431	55,140	280,380	52,852	1,482	70,490	15,012	24,173	0	868	511,817
	NINE-COUNTY TOTAL	184,174	175,992	369,681	1,293,884	825,177	30,864	232,317	34,792	80,762	36,175	6,679	3,270,497

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[a] See text for estimation procedures

TABLE 11

WASTES GENERATION BY DSA AND BY WASTES SOURCE
(tons per year)

DSA 1	Restaurants and Hotels 2	Institutions Private (Schools and Colleges) 3	Public Offices and Facilities 4	Health Services (Private) 5	Commercial and Service Establishments (Private) 6	Construction and Demolition (Public and Private) 7	Agriculture 8	Extractive Industry 9	Canning and Preserving 10
01 01	8,546	1,543	90,132	8,935	58,695	84,319	0		2,338
02	36,474	8,215	128,568	41,107	484,616	546,961	18,237		29,381
03	2,141	572	53,563	2,781	18,041	59,485	0		451
04	2,008	263	12,992	1,036	25,642	188,481	52,790		1,152
05	297	0	2,618	114	3,399	78,255	59,512		33
06	701	122	25,989	1,276	8,009	52,308	45,737		56
02 01	8,794	1,376	27,334	5,856	91,824	176,394	1,340		1,091
02	9,205	1,932	44,026	9,971	82,592	363,926	8,983		751
03	2,119	206	7,605	1,360	18,986	27,598	491,499		1,603
03 01	171	0	747	61	572	5,198	333,612		0
02	6,237	3,201	23,752	7,289	63,774	128,046	39,016		0
04 01	6,633	4,656	67,469	7,053	54,065	77,224	98,991		0
05 01	3,951	4,835	39,858	17,332	36,733	63,570	0		306
02	5,597	2,408	30,229	12,669	34,760	186,459	0		78
03	77,753	2,160	56,367	15,591	411,953	428,279	0	OMITTED FROM THIS STUDY	3,390
04	12,665	697	54,542	739	255,132	52,308	0		6,696
05	1,768	522	10,036	6,020	25,189	41,458	0		768
06	812	354	6,744	2,225	10,291	42,366	0		11
07	4,839	1,783	12,855	2,694	75,013	28,423	0		4,625
08	1,246	164	37,088	50	42,570	14,727	0		3,941
09	1,722	995	4,264	4,290	18,296	12,747	0		852
10	846	1,082	7,784	187	13,145	46,821	0		0
11	918	453	12,013	1,044	15,960	4,950	0		56
12	1,867	1,059	7,140	1,391	26,236	4,290	0		6
06 01	1,920	309	4,961	1,033	21,310	77,843	6,368		0
02	6,557	697	17,938	2,587	120,472	118,187	367		1,013
03	723	30	3,281	232	4,545	50,451	3,030		0
04	19,634	3,029	50,427	15,728	183,053	351,797	34,937		779
07 01	5,174	34,653	12,871	12,874	72,628	139,514	8,055		1,809
02	2,717	575	6,992	1,132	33,266	75,037	8,055		501
03	5,258	99	22,148	1,299	38,314	116,785	15,271		4,864
04	1,215	80	2,400	1,105	7,746	16,130	229,355		3,829
05	5,814	655	15,256	5,456	40,246	164,224	18,974		3,145
06	6,652	3,040	18,098	6,134	50,629	134,358	8,409		6,161
07	17,557	2,610	69,153	15,442	177,422	264,756	76,751		42,967
08	84	0	476	0	4,370	0	76,796		111
08 01	2,766	23	4,999	194	10,577	22,647	199,188		0
02	2,980	575	19,005	3,155	23,204	39,396	304,473		0
09 01	1,509	149	2,964	892	15,385	16,913	119,217		1,993
02	1,749	149	2,835	137	5,730	16,088	161,744		189
03	682	156	983	671	4,134	6,765	337,973		167
04	6,679	861	15,187	6,778	55,974	127,675	511,817		1,837
TOTAL	286,981	86,288	1,033,689	225,920	2,744,498	4,453,159	3,270,497		126,948

TABLE 11 (Continued)

DGA	Other Food Processing 11	Tobacco Industry 12	Ordnance and Accessories 13	Textiles and Apparel 14	Lumber and Wood Products 15	Furniture and Fixtures 16	Paper and Allied Products 17	Printing, Publishing and Allied 18	Chemicals and Allied 19	Petroleum Refining 20
01 01	5,028	0	0	1	694	4,172	5,153	7,657	17,062	OMITTED FROM THIS STUDY
02	63,289	0	0	603	19,042	23,542	33,804	55,847	15,814	
03	973	0	0	0	3,383	443	2,345	898	4,721	
04	2,481	0	0	17	195	5,623	8,288	1,809	5,780	
05	67	0	0	0	0	887	0	0	0	
06	125	0	0	80	0	0	0	739	0	
02 01	4,715	0	0	27	1,236	3,729	589	6,733	14,032	
02	3,266	0	11	2	369	484	38	6,245	7,964	
03	6,936	0	0	0	781	0	35,296	1,479	8,974	
03 01	0	0	0	0	0	0	0	0	0	
02	1,551	0	0	7	3,383	524	213	4,225	0	
04 01	5,520	0	0	256	217	645	351	4,476	123	
05 01	780	0	0	19	0	20	0	158	16	
02	202	0	0	7	109	121	0	884	16	
03	8,646	0	0	1,314	260	16,850	3,699	57,814	6,322	
04	17,084	12	0	1,450	1,106	6,974	9,993	88,431	5,961	
05	1,956	0	0	73	0	1,552	0	5,637	25	
06	19	0	0	0	0	0	0	436	0	
07	11,796	52	0	936	954	8,163	2,796	11,116	994	
08	10,057	0	0	285	2,776	11,448	677	1,545	1,141	
09	2,177	0	0	47	0	665	0	119	189	
10	10	0	0	4	0	0	0	40	41	
11	135	0	0	0	0	0	0	26	0	
12	10	3	4	4	22	403	0	211	0	
06 01	0	0	0	7	87	0	0	449	0	
02	8,448	0	0	124	1,366	6,228	6,244	9,361	8,942	
03	0	0	0	2	0	0	0	370	0	
04	6,526	0	22	72	5,943	8,788	1,542	20,371	7,045	
07 01	756	0	1,027	1	694	0	1,831	7,499	550	
02	207	0	938	1	2,407	1,391	0	2,971	246	
03	2,037	0	10,561	0	0	181	376	3,525	1,191	
04	1,604	0	0	0	22	806	414	449	591	
05	1,320	0	0	50	499	806	3,360	1,848	82	
06	2,587	0	0	13	5,574	6,974	8,002	5,321	1,544	
07	18,019	0	2,490	299	3,947	2,358	6,269	21,665	5,633	
08	43	0	0	0	0	0	0	0	0	
08 01	6,401	0	0	0	0	0	0	422	0	
02	9,248	0	0	0	499	0	0	766	0	
09 01	1,893	0	0	30	14,943	40	0	2,139	25	
02	183	0	0	0	6,658	81	0	53	0	
03	164	0	0	0	13,794	564	0	343	222	
04	1,749	0	0	21	4,251	367	0	1,373	66	
TOTAL	208,008	67	15,053	5,752	95,211	115,329	131,280	335,450	115,312	

TABLE 11 (Continued)

DEA	Rubber and Plastic Products 21	Leather and Allied 22	Stone, Clay, and Glass 23	Primary Metals 24	Fabricated Metals 25	Nonelectrical Machinery 26	Electrical Machinery 27	Transportation Equipment 28	Professional and Scientific Instruments 29	Miscellaneous Manufacturing 30	Nonclassifiable 31
01 01	207	212	1,340	3,796	7,194	3,647	673	682	715	162	1,247
02	1,281	252	62,404	24,066	50,731	33,578	6,729	7,588	1,311	1,160	4,314
03	17	0	0	0	5,047	352	0	4,639	3	117	0
04	0	0	5,887	8,392	3,511	79	474	21,181	0	72	99
05	0	0	2,699	0	0	0	0	0	0	12	0
06	0	0	0	0	909	25	0	0	8	17	25
02 01	73	479	12,191	1,508	12,208	1,953	760	2,053	2,137	334	973
02	15	0	6,394	3,479	175	2,426	226	316	727	40	1,297
03	444	0	10,035	21,502	2,322	125	0	210	0	70	50
03 01	0	0	0	0	0	0	15	0	0	0	0
02	85	0	3,677	841	357	67	2,085	495	0	152	2,169
04 01	19	329	1,395	4,253	552	309	39	34	70	27	648
05 01	0	0	779	0	13	17	9	0	0	0	299
02	0	0	127	0	0	0	0	51	0	75	524
03	2	3	6,757	5,680	2,510	1,380	158	285	138	688	3,815
04	175	237	1,703	1,259	16,408	5,157	1,796	7,825	365	1,112	623
05	0	0	0	0	13	42	18	3	35	25	149
06	0	0	0	0	0	8	0	0	0	5	75
07	68	12	6,431	1,299	3,251	3,459	408	665	68	516	574
08	77	459	2,355	1,945	20,204	2,112	757	1,371	0	461	150
09	0	0	36	0	767	0	42	0	0	55	75
10	5	0	0	0	915	29	0	0	0	15	75
11	0	0	0	0	0	0	0	0	0	70	75
12	0	3	0	0	108	0	9	0	3	37	125
06 01	0	0	815	0	114	0	0	3	0	37	224
02	175	207	3,750	9,853	10,815	2,288	1,838	397	96	357	474
03	0	0	0	0	0	0	3	0	0	0	50
04	376	5	9,438	1,810	7,181	7,005	27,788	1,775	662	551	2,194
07 01	0	0	326	67	168	351	25,018	3,631	1,810	2	4,189
02	5	0	235	0	343	2,334	17,300	88	345	0	898
03	11	0	652	0	1,252	999	11,962	268	662	5	349
04	3	7	706	0	121	489	0	285	0	0	75
05	11	0	54	27	209	590	501	10	169	12	524
06	46	0	31,609	3,190	5,458	1,447	2,055	309	166	259	524
07	687	0	14,057	1,911	9,301	21,283	7,917	7,587	131	982	2,967
08	0	0	0	0	0	0	0	0	0	0	0
08 01	0	0	670	0	27	0	0	0	0	0	0
02	0	0	797	0	2,187	493	0	173	58	2	748
09 01	0	0	0	54	983	238	6	0	0	107	0
02	0	0	0	47	202	17	0	0	0	120	973
03	11	0	0	0	0	25	0	61	0	0	0
04	0	396	1,558	162	727	577	116	95	383	25	823
TOTAL	3,793	2,601	188,877	95,141	166,083	92,901	108,702	62,080	10,062	7,681	32,393

TABLE 12

POPULATION BY DSA

Disposal Service Area		Population Estimate 1966
Code	Name	
01 01	Berkeley	117,870
02	Oakland	691,900
03	Alameda	69,200
04	Fremont	122,250
05	Pleasanton	25,300
06	East Alameda County	32,500
02 01	West Contra Costa	235,006
02	Central Contra Costa	280,530
03	East Contra Costa	60,340
03 01	West Marin	10,616
02	East Marin	127,051
04 01	Napa County	152,467
05 01	Richmond	90,540
02	Marina-Pacific Heights	67,100
03	Central	93,295
04	South of Market	28,260
05	Western Addition	52,815
06	Twin Peaks-Buena Vista	63,025
07	South Van Ness	43,570
08	Potrero-Bayshore	45,800
09	Outer Mission	83,000
10	So. Frway-Mt. Davidson	58,075
11	Lake Merced	29,620
12	Sunset	92,400
06 01	Daly City	65,000
02	South San Francisco	105,100
03	Pacifica	40,500
04	Central San Mateo	303,320
07 01	Palo Alto	68,593
02	Mountain View	51,178
03	Sunnyvale	86,015
04	Gilroy-Morgan Hill	24,201
05	Los Gatos	174,684
06	Los Altos	179,138
07	San Jose	344,775
08	Remainder of County .	3,091
08 01	Vacaville	29,491
02	Fairfield	65,104
09 01	Healdsburg	17,690
02	Santa Rosa	82,810
03	Western Sonoma	8,765
04	South Sonoma	78,375
NINE-COUNTY TOTAL		4,400,360

NOTE: For data sources and method of estimation see Appendix F

Household (Residential) Income

Income is one of the variables used in explaining variation in wastes generation. The manner in which income level affects wastes generation is fairly obvious and needs no stressing here. Suffice it to say that wastes generation is a function of extent to which a product is used, variety of products purchased, and frequency of purchase of a particular product (and hence of discard); and these, in turn, are functions of income.

The primary source of income data was the 1960 Population and Housing census. Among the other sources was the publication Sales Management, Survey of Buying Power 1966 [10]. The difficulty in using both sources was the inability to estimate corresponding figures for the 42 functional boundaries (DSA's) defined in this study. Using the 1960 census figures as a benchmark, the development of data to correspond to 1965 would involve using population and/or employment data. The Sales Management figures would be heavily biased toward "big city incomes" and could not be used to represent the average for the DSA. Some comparisons were attempted between these figures and those available from the 1966 census in Santa Clara County. The difficulty in estimating income for 1966 and the very nature of the method of estimation precluded the use of income variable at the DSA level in the present study. Since employment, population, and land could be satisfactorily used in estimating wastes data at the DSA level, the addition of the income variable, for which data were less than satisfactory, would have served no useful purpose in the study. However, income data which are available in sufficient detail at the county level will be used in later phases of the investigation.

Land Use by DSA's

Land-use information can be used in two important ways. Firstly, it can be used to constitute one of the explanatory variables such as is done with agricultural wastes in the present report. Secondly, it also can be used in conjunction with land-use planning for the region to suggest future locations of solid wastes disposal sites as part of the overall regional management issues. This latter aspect will form an important subject for future research investigations.

The research plan called for the use of data on land use (for 1965 or 1966) to be obtained either from the Bay Area Transportation Studies or from the Bay Area Simulation Studies (BASS). The results from the latter were published recently and were available for this study [11]. Agricultural land-use information was, however, aggregated with vacant land and was not separately available. Separate tabulations of required agricultural land-use information were made by the planning and economics research team with data obtained from the County Agricultural Commissioner's reports by each of the functional boundaries (DSA's). Information on industrial land available from the BASS studies is still under investigation. However, an attempt was made to tabulate the industrial land-use information from the BASS studies for use in later phases of this study. Data tabulated thus far are given in Appendix G.

Results of the Solid Wastes Generation in the Nine-County Bay Area

Important aspects and final tabulations of the results developed thus far are described in Table 13. Essentially, the table presents summary information on total solid wastes estimated for the nine-county Bay Area by major sources of wastes, namely, residential, agricultural, commercial and nonmanufacturing, and manufacturing (industrial) categories. Corresponding figures on population and employment are given for comparison. The comparable data are summarized for each of the 42 functional boundaries (DSA's) defined in this study. The last column in the table gives the totals for the entire study region.

TABLE 13

SOLID WASTES PRODUCTION IN TERMS OF DISPOSAL SERVICE AREA, SOURCE, POPULATION, HOUSEHOLDS, AND EMPLOYMENT

Disposal Service Area		Residential			Agricultural		Commercial, Nonmanufacturing and Public		Manufacturing Industry		Total
Code	Name	Population 1	Household Wastes (tons) 2	Household Wastes Per Capita (tons) 3	Employment 4	Wastes (tons) 5	Employment 6	Wastes (tons) 7	Employment 8	Wastes (tons) 9	Wastes (tons) 10
01 01	Berkeley	117,870	43,209	.36658	152	0	46,098	252,170	8,397	61,979	357,358
02	Oakland	691,900	268,380	.38789	1,301	18,237	196,713	1,245,941	59,634	434,736	1,967,294
03	Alameda	69,200	26,229	.37903	123	0	21,677	136,583	3,551	23,389	186,201
04	Fremont	122,250	33,577	.27466	2,516	52,790	15,577	230,422	11,062	64,840	381,629
05	Pleasanton	25,300	3,277	.12953	519	59,512	3,584	84,683	218	3,699	151,171
06	East Alameda County	32,500	8,779	.27012	1,109	45,737	10,742	88,405	397	1,984	144,905
02 01	West Contra Costa	235,006	91,380	.38884	194	1,340	59,756	311,578	9,034	66,821	471,119
02	Central Contra Costa	280,530	96,295	.34326	1,602	8,983	47,594	511,652	4,333	34,226	651,156
03	East Contra Costa	60,340	23,198	.38445	3,812	491,499	8,615	57,874	10,287	89,827	662,398
03 01	West Marin	10,616	5,320	.50113	169	335,612	333	6,749	5	15	347,696
02	East Marin	127,051	44,378	.34929	1,029	59,016	30,466	232,299	2,501	19,831	355,524
04 01	Napa County	152,467	62,828	.41208	3,731	98,991	38,584	217,100	3,153	19,263	398,182
05 01	Richmond	90,540	35,753	.39489	66	0	28,498	166,279	332	2,416	204,448
02	Marina-Pacific Heights	67,100	22,616	.33705	10	0	27,003	272,122	223	2,194	296,932
03	Central	93,295	39,700	.42553	416	0	158,363	992,103	13,739	119,710	1,151,513
04	South of Market	28,260	10,468	.37042	13	0	86,246	376,083	23,817	174,367	560,918
05	Western Addition	52,815	15,061	.28517	18	0	12,431	84,993	1,239	10,296	110,350
06	Twin Peaks-Buena Vista	63,025	22,909	.36349	14	0	6,388	62,792	46	554	86,255
07	South Van Ness	43,570	11,369	.26094	13	0	26,196	125,607	9,213	58,183	195,159
08	Potrero-Bayshore	45,800	11,195	.24443	87	0	21,647	95,845	9,354	61,760	168,800
09	Outer Mission	83,000	31,279	.37686	34	0	8,069	42,314	914	5,023	78,616
10	So. Frwy-Mt. Davidson	58,075	24,524	.42228	54	0	7,183	69,865	172	1,134	95,523
11	Lake Merced	29,620	12,911	.43589	4	0	8,096	35,338	71	362	48,611
12	Sunset	92,400	43,762	.47361	41	0	9,997	41,983	96	948	86,693
06 01	Daly City	65,000	24,757	.38088	145	6,434	9,658	107,376	138	1,736	140,303
02	South San Francisco	105,100	39,788	.37857	91	367	41,775	266,438	9,794	71,976	378,569
03	Pacifica	40,500	13,349	.32960	47	3,049	3,537	59,267	35	425	76,090
04	Central San Mateo	303,320	124,304	.40981	2,499	34,852	79,883	623,668	19,100	109,873	892,697
07 01	Palo Alto	68,593	26,632	.38826	274	8,055	39,654	277,714	13,349	49,729	362,130
02	Mountain View	51,178	17,840	.34859	165	8,055	13,546	119,719	8,625	30,210	175,824
03	Sunnyvale	86,015	31,787	.36955	442	15,271	20,447	183,903	22,619	38,895	269,856
04	Gilroy-Morgan Hill	24,201	8,817	.36432	2,009	229,355	3,684	28,676	1,467	9,401	276,249
05	Los Gatos	174,684	60,142	.34429	1,417	18,974	21,678	231,651	1,865	13,217	323,984
06	Los Altos	179,158	65,144	.36365	1,468	8,409	25,449	218,911	7,879	81,240	373,704
07	San Jose	344,775	117,284	.34018	2,896	76,751	80,480	546,940	32,368	170,470	911,445
08	Remainder of County	3,091	1,143	.36978	4,726	76,736	1,294	4,990	29	154	83,023
08 01	Vacaville	29,491	11,492	.38968	1,982	199,188	5,420	41,206	1,402	7,520	259,406
02	Fairfield	65,104	20,640	.31703	2,300	304,473	13,794	88,315	2,593	14,971	428,399
09 01	Healdsburg	17,690	11,065	.62549	1,586	119,217	5,894	37,808	1,920	22,451	190,541
02	Santa Rosa	82,810	37,110	.44813	1,522	161,744	3,172	26,688	515	8,523	234,065
03	Western Sonoma	8,765	4,180	.47690	1,390	337,973	1,903	13,391	812	15,351	370,895
04	South Sonoma	78,375	35,895	.45799	829	511,817	25,530	213,154	1,861	15,025	775,891
	NINE-COUNTY TOTAL	4,400,360	1,639,766	.37264	42,815	3,270,497	1,256,834	8,830,535	297,959	1,918,724	15,659,522

Sources:

Column 1	- Table 12	Column 5	- Table 10
Column 2	- Table 4	Column 7	- Table 11
Column 3	- Column 2 divided by Column 1	Column 9	- Table 11
Columns 4, 6, and 8	- Table 5	Column 10	- Sum of Columns 2, 5, 7, and 9

Some of the highlights of the results are as follows:

1. Of the total wastes (15.66 million tons) generated in the nine-county Bay Area during 1966, nearly 56.4 percent came from commercial, nonmanufacturing sources; nearly 21.0 percent from agricultural sources; about 12.3 percent from industrial sources; and about 10.4 percent from household sources.

2. Of the total residential (household) wastes (1.64 million tons), nearly 83 percent of it came from single-family dwellings. These wastes have a composition differing from that of the remaining 17 percent which came from multiple-family dwellings. On the basis of a total population of 4.4 million, the household wastes accounted for about 2 pounds per day per capita.

3. Of the total 3.27 million tons of agricultural wastes, cattle manure constituted the largest amount — nearly 1.3 million tons. All other livestock and poultry wastes, including dead animals, accounted for approximately 1.24 million tons. The remaining 0.73 million tons of agricultural wastes came from orchards, vegetables, and field crops.

4. The manufacturing (industrial) wastes, accounting for nearly 1.9 million tons in the Bay Area, came from a variety of sources (see Table 11 for details). Canning, preserving, and other food processing accounted for nearly 0.33 million tons of wastes. Printing, publishing, and allied sources generated 0.34 million tons. The remaining wastes came from a variety of sources.

5. In terms of wastes generation, the major portion came from sources in the category of commercial, nonmanufacturing, including public offices. This major source accounts for nearly 8.8 million tons of wastes. It is well known that the greater portion of these wastes consists of paper, and that paper is the largest constituent of total wastes.

6. On the whole, if the total wastes (15.66 million tons) were related to the total population of the Bay Area (4.4 million), the per capita wastes generation per day in 1966 would have been around 19.5 pounds. This figure includes nearly 4.0 pounds of agricultural wastes (sometimes omitted from calculations), 11.0 pounds from commercial nonmanufacturing wastes, approximately 2.5 pounds from industrial wastes, and about 2.0 pounds from household wastes.

The above information can be used in a variety of ways. A comparison of the solid wastes data based on estimates made by disposal site operators (Table 2) with those given in the summary table gives an indication of the amount and nature of wastes that did not enter the regular disposal sites. In fact, according to the data in the summary table, of a total of 15.66 tons of wastes generated during the year 1966, only about 4.24 million tons ended up in disposal sites. The latter figure is estimated on the basis of 11,609 tons per day (cf. Table 2). This means that only about 27.1 percent of the total wastes generated in the nine-county Bay Area is disposed of in regularly operated disposal sites. If agricultural wastes are not taken into consideration, the wastes disposed of in sites accounts for approximately 34.2 percent.

The implication of the above figures is obvious with respect to the validity of estimates of the life span of existing sites. As more and more of the industrial and agricultural wastes are directed to the disposal sites, the supply of disposal site facilities could diminish at a rate much more rapid than heretofore, and thereby create a near-crisis situation, unless meaningful alternative solutions are developed beforehand.

The present implications of the enormous quantities of wastes listed in Table 13, and, more importantly, their effect in the future on the resources of the region, constitute one of the more important issues to be considered in effective wastes management. Before these implications can be discerned, it is necessary to examine a host of factors, of which the following warrant special consideration:

1. Physical and chemical properties of wastes by source of wastes;
2. Meaningful forecasts of the quantities of the individual constituents of the total wastes load, with a realistic appraisal of changes in composition;
3. Survey of existing transportation and disposal techniques;
4. Possible breakthrough in technology; and
5. Recognition of the need for regional management with its attendant influence on existing practices of solid wastes management.

These factors, in turn, would lead to others, such as private and public expenditures by type of function, forecasts of increase in costs, incidence of costs on different private and public bodies, and the broader questions of efficiency, equity, and incentives for regional management.

Public and Private Expenditures for Refuse Removal and Disposal

An important element of the whole question of effective wastes management is the expenditure on the various functions relating to wastes management incurred by different segments of the community such as private households, industry, agriculture, and those public agencies which either are in the business of wastes management or which supervise activities pertaining to it. Before embarking upon empirical research on the subject, an essential step to be taken is the establishment of a detailed accounting procedure by means of which it would be possible to determine true costs (avoiding duplications and omissions) in terms of private and public expenditure by type of function and by the individual segment which pays the bills. The development of such a procedure is one of the activities of the planning and economics team. A report on the progress made thus far in this phase of the study is the subject matter for this section.

The collection, transfer, and disposal of solid wastes is handled by scavenger companies, private commercial haulers, individual householders, and public agencies. Several different combinations of services are possible, ranging from scavenger company operations (involving one or more companies) to part-private, part-public operations, to all-public agency operations. There are a large number of scavenger companies, private collection companies, and private disposal site owners operating under an even larger number of public jurisdictions in the nine-county San Francisco Bay Area. In addition to nine county governments, there are ninety-one cities, thirty-five sanitary districts, nineteen county sanitation districts, one garbage disposal district, and one sanitation and flood control district empowered by law to collect and dispose of refuse. In addition, some fifteen sewer and sewer maintenance districts are empowered to provide for the "collection, treatment, and disposal of sewage and industrial wastes." While few of these public bodies are actively engaged in direct collection and disposal services, almost all incur some regulatory and administrative expense.

In addition to the expenditures by the 171 local public bodies specifically concerned with the problem of solid wastes disposal, there are the wastes disposal expenditures associated with other special districts and various state and federal facilities scattered about the region. These range from local school districts, which arrange for collection services from private companies in the same manner as would any commercial operation, to the State Parks and large military installations which dispose of all refuse on their own premises and operate their own collection and disposal systems. Additionally, many of the sanitary districts operate sewage disposal plants which produce sludge and sewage wastes that must be disposed of elsewhere at public expense, either by another public agency or by a private disposal company.

According to the report Refuse Disposal Needs issued by the Association of Bay Area Governments [12], from 90 to 95 percent of the people living in the Bay Area in 1963 were provided with regular collection and disposal service. The bulk of this service was handled privately. Of the eighty-two major refuse collection companies in operation in July of 1963, only four were publicly operated, namely, Berkeley, San Leandro, Dixon, and San Quentin Prison. For the most part, the private companies operate under exclusive franchises or contracts issued by counties, cities, or sanitary districts. A few collection companies operate without franchise in the unincorporated areas. Some of the cities issue a franchise for household refuse only, and leave commercial pickups to open competition. The greater number of the disposal sites are privately owned and operated, although subject to public regulation. The publicly owned sites are in some cases used exclusively for publicly collected refuse, in other cases by private companies, and in many cases directly by individual citizens and enterprises.

Accounting for total expenditures on wastes removal, handling, transfer, disposal, and supervision by public bodies covers a wide range of activities. Initially, for data collection purposes, collection, handling, and transportation of refuse were treated as one function, and the operation of the disposal site as a separate function. The many different combinations of private and public agencies providing these functions fall into three general categories. Examples of the combinations are given in Table 14.

TABLE 14

EXAMPLES OF COMBINATIONS OF PRIVATE AND PUBLIC COLLECTION AND DISPOSAL SERVICES

Cases	Collection and Transport Agent	Disposal Site Operation
1. Scavenger Co. to Own Site	Private Scavenger Co. A	Private Scavenger Co. A
2. Scavenger Co. to Private Site of Another Company	Private Scavenger Co. A	Private Scavenger Co. B
3. Scavenger Co. to Public Site	Private Scavenger Co. A	Public Agency C
4. Public Agency to Private Site	Public Agency C	Private Company A
5. Public Agency to Own Site	Public Agency C	Public Agency C
6. Public Agency to Public Site of Another Agency	Public Agency C	Public Agency D
7. Commercial Haulers to Private Company Site	Commercial Haulers	Private Company A
8. Commercial Haulers to Public Site	Commercial Haulers	Public Agency C
9. Self-Service to Private Company Sites	Self-Service	Private Company A
10. Self-Service to Public Site	Self-Service	Public Agency D
11. Commercial Haulers to Nonsite	Commercial Haulers	Not-to-Site
12. Self-Service to Nonsite	Self-Service	Not-to-Site

In the first category, wastes are picked up at the source as part of a regular collection service and taken to a disposal site (rows 1-6 in Table 14). The source of the wastes may be a household, a business, an agricultural unit, or a governmental office. The collection service may be provided either privately by a scavenger company or by a public agency. The disposal site may be privately operated by the same company as the collection service or by a different one, or it may be publicly operated by the same jurisdiction as the collection service or by a different public agency. Thus, there are several different possible combinations within this category. Costs of the transportation and disposal functions may be determined as the sum of the revenues of the operators providing the relevant services. Care must be taken, however, that the funds paid to the disposal site operator by the collection company or operator are not counted twice in estimating costs, i.e., once as revenue of the disposal site, and once again as revenue of the collection company or agency. Similarly, in cases in which the collection and transfer operation and/or the disposal operation are carried on by a public agency, double counting of public expenditures should be avoided. A distinction must be made between such expenditures by the public agency for administration, management, and supervisory functions, and these costs should be examined in detail.

In the second category, wastes are transferred directly to a disposal site by a private hauler or the consumer, i.e., by some party other than a scavenger company or a public agency (Table 14, rows 7-10). Disposal costs are inclusive and may be obtained, but transportation costs must be estimated separately.

In the third category, wastes are not handled by a scavenger company (or a public agency), nor are they taken to a disposal site (Table 14, rows 11 and 12). The wastes may be burned or buried on the premises, spread on agricultural land, disposed of at sea, sold or otherwise reused, or disposed of by some other means. In estimating expenditures in this category, the amounts of solid wastes and the associated expenditure for transportation and disposal must be determined one by one.

The three categories described above are listed in increasing order of difficulty with respect to obtaining accurate data, and in decreasing order with regard to reliability of the applied estimation procedures. The selected data collection system must be able to account for all expenditures made in the management of solid wastes. The expenditures may be measured in terms of either the revenues collected by those providing the service, or by the expenditures made by the users. Given a particular source of wastes, the wastes generated either will be collected by a regular collection service (category 1) or removed by the consumer in some other way (categories 2 and 3). The expenditure incurred by the consumer in any of the three categories is equal to the revenue of the party that provided the service, and thus can be accounted for by summing all such revenues. In those instances in which some of the producers of wastes also perform some of the operations of collection and disposal (termed "self-service units"), the value of those services performed in accomplishing the wastes disposal should be estimated. This value or cost should be added to that of the services supplied by the regular collection and disposal site operators so as to arrive at a true total cost for the entire region.

Another question of interest in the study of the expenditures involved in wastes management is that of separating private and public expenditures by type of function. The fact that public wastes sources do not pay directly for their wastes disposal operations does not mean that these operations do not cost anything. These operations are paid for indirectly by taxes (direct subsidy from the taxpayers to the public agency involved) and by fees paid by private collection disposal companies for indirect services. Although the public collection agencies generally are exempted from paying franchise and administrative fees and taxes, these elements should not be excluded when estimating the true costs of operations and when making comparisons with similar costs of operations by private agencies. In other words, in arriving at estimates and in making comparisons between private and public operations, the items of costs should be made uniform by avoiding possible omissions or double countings, as the case may be. Some of the problems in arriving at estimates are described schematically in Tables 15 and 16.

TABLE 15

PRIVATELY OPERATED DISPOSAL SITES: REVENUES AND EXPENDITURES

Sources of Revenue	Experditures
1. Disposal Fees from a. private scavenger companies b. public collection agencies c. commercial haulers All three will have collected wastes from households businesses industry public agencies Their disposal fees will have already been counted in the revenues of the collectors — disposal fees listed here are thus a subcategory of total revenue-expenditure of operation. d. self-service haulers who may be households, businesses, industry, agricultural units, or public agencies Their disposal fees have not been previously accounted for and are new items. 2. Additional Revenue from Sale of Refuse and Salvage Operations Note: Private-source disposal fees may be lumped together, but public-source fees must be kept separate, and each source indicated to keep track of separate public agency expenditures.	Processing Costs equipment labor fill and cover material general administration and maintenance extra costs for salvage operations, if any Land Costs Land could be: owned by site operator leased from another private party leased from public agency (could even be negative or zero cost if refuse is of high quality and valuable for fill) Public Fees business license special disposal fees for health inspections, franchise privilege Profit (to be recognized)

TABLE 16

PUBLICLY OPERATED DISPOSAL SITES: REVENUES AND EXPENDITURES

Sources of Revenue	Expenditures
1. Disposal Fees from a. private scavenger companies b. public collection agencies (either accounting transfer if site operated by same agency as does collecting, or other public agency) c. commercial haulers These disposal fees will have already been counted in calculating revenue of collectors – disposal fees listed here are thus a subcategory of total revenue-expenditure of operation. d. self-service haulers who may be households, businesses, agricultural units, industry, or public agencies (again, same or different) 2. Salvage Fees from Sale of Refuse 3. Subsidy (if operated at loss) Note: Private-source disposal fees may be lumped together, but public-source fees must be kept separate and each source indicated to keep track of separate agency expenditures.	Processing Costs equipment labor fill and cover material general administration and maintenance extra cost for salvage operation Land Costs Land could be: already owned purchased for this purpose leased from private owner leased from other agency (land costs could be zero or even negative if refuse is of high quality and valuable for fill) Additional Costs Site may operate at cost, or operate at deficit in which case additional revenue from taxes are necessary to balance account.

The public expenditures could be incurred at the local level by city, county, or special districts, or at higher levels by state and federal agencies. The nature of the function could be simply that of a customer, collecting agency, disposal agency, self-service unit, supervisor or combination of these functions. The procedures for collecting data on expenditures by functional lines and by type of agency, private and public, (if public, at which level), should be devised with proper care and the avoidance of double counting. Finally, the expenditures should be estimated at the functional boundary (DSA) level. Where expenditures are not readily divisible and cannot be determined along these lines, e.g., county and state road sanitation expenses, the data should be collected for the larger area and appropriately apportioned among the DSA's. Following these steps, each governmental body involved in any way with the collection, handling, treatment, or disposal of solid wastes should be listed. These activities should be subdivided into appropriate agencies as necessary, and the net expenditure by each governmental unit or department recorded. Use could be made of data on the gross revenues from collection, transfer, or disposal obtained by private companies engaged in systematic, regular collection and disposal operations.

Finally, those private companies engaged in occasional or special hauling should be listed along with their gross revenues. Row totals thus would be the sum of all of the monies collected by any private company, or spent by any governmental body on all aspects of solid wastes management within the area, while column totals would reveal the total money spent in each area by function.

In the preceding discussion, a brief description was given of the difficulties which may be encountered in any attempt at arriving at estimates of true and comparable costs of solid wastes management by the different agencies. Possible approaches are presently under consideration, with the view of making them operational for the Bay Area, and thereby arrive at procedures which would be more general in application. The first step in the research, therefore, will be an investigation of the various ramifications with respect to a metropolitan area within the Bay Area.

IV. OPERATIONS RESEARCH IN SOLID WASTES

A comprehensive wastes generation model was described in Chapter III of the First Annual Report [1] of the project. During the second year of the study, attention of the operations research group was focused on wastes collection, treatment, and disposal. A series of models was developed which deal with this general topic at different levels in the wastes management structure and utilizing different planning horizons.

The subjects receiving special consideration were:

1. Optimal location of treatment plants and disposal sites.
2. Determination of the least cost flow pattern of wastes from origin, via existing transportation networks, to treatment plants and ultimately to disposal sites.
3. Optimal operating policies for treatment plants in the face of randomly varying wastes loads.

The models are described in detail in separate reports [13,14] of the project and hence are herein described only briefly.

OPTIMAL ACTIVITY LOCATIONS

The problem of optimal activity locations is one which is concerned with locating a treatment plant or disposal site or group of sites to serve a certain number of sources (wastes generators) in the most economical manner; in other words, for a number of sources — given their location requirements and associated shipping costs — to find the prescribed number of disposal sites, their locations and their capacities. This problem, as is apparent, is usually long term in outlook and the planning horizon approximates 15 to 20 years.

Stated mathematically the main problem reduces to: Given a set of generation points, n, their locations (x_i, y_i) $i = 1, 2, \ldots, n$ and their requirements w_i, $i = 1, 2, \ldots, n$. Find disposal sites (x_j, y_j), $j = 1, 2, \ldots, m$ and minimize $F(x,y)$ subject to

$$F(x,y) = \sum_{i=1}^{n} \sum_{j=1}^{m} \alpha_{ij} \, w_i \, \ell_{ij}$$

where

$$\ell_{ij} = \left[\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2\right]^{k/2}$$

$$\alpha_{ij} = \begin{cases} 1 \text{ if generation point } i \text{ is assigned to site } j; \\ 0 \text{ otherwise.} \end{cases}$$

A general power k was considered in the distance (or cost) expression, allowing treatment of all possible cases where the power of cost is more than unity. This problem lends itself to different solution procedures depending on the number of disposal sites that are prescribed.

The single "free" site problem has been considered and solved in the literature [15]. It was not considered desirable here since the site thus chosen may not be practical. The single-site problem occurs when given a set of generation points, their location requirements, and associated shipping costs, a single-site location is required such that the sum of the total shipping cost from all generators to this single-site be minimized. A quadratic approximation search procedure was developed that converged to an optimal-site location faster than other presently known methods. This search procedure is based both on the quadratic and the Fibbonacci approximations which are used alternately until the directional vector becomes very small or the distance between two successive site locations is negligible.

The multiple-site problem arises when a prescribed number (greater than one) of sites have to be located in order to serve a given set of generation points at a minimum total transportation cost. Two general assumptions were made: 1) There is no capacity restriction on the Sources, and 2) the unit transportation costs are independent of the amount transported. It should be borne in mind that complete enumeration of all possible assignments of sources to destinations can always be resorted to, but that the time and cost involved in doing so for any reasonably large-size real-life problem would be prohibitive. A branch and bound algorithm was developed which results in the optimal activity location. To express this mathematically, let

L = set of all locations, generation points and sites, $|L| = n$
S = set of sites, $S \subset L$, $|S| \leq m$
D = set of generation points, $D \subset L$, $|D| \leq n - m$
A = set of unassigned locations or where sites could be located, $A \subset L$, $|A| \leq n$
S_o = optimal set of sites, $S_o \subset L$, $|S_o| = m$
D_o = optimal set of generation points, $D_o \subset L$, $|D_o| = n - m$

then

$$S \cap D \cap A = \phi \quad \text{(the null set)}$$

$$S \cup D \cup A = L$$

and at optimality

$$A = \phi$$

and

$$S_o \cup D_o = L$$

Then the original problem can be rewritten in the following form: Find α_{ij} and min $F(\alpha_{ij})$ subject to $|S| = m$, where

$$F(\alpha_{ij}) = \sum_{j \in L} \sum_{i \in S} \alpha_{ij} \, c_{ij}$$

and

$$c_{ij} = w_i \cdot \ell_{ij}$$

Let min $F(\alpha_{ij})$ be $Z(S)$, then

$$Z(S) = \min \sum_{j \in L} \sum_{i \in S} \alpha_{ij} c_{ij}$$

$$= \sum_{j \in L} \min_{i \in S} c_{ij}$$

and the problem thus is to find Z(S) subject to $|S| = m$. The procedure developed to achieve this objective is to construct the set by adding one location at a time. After a number of iterations, the site set will equal (n-m) in which case a feasible solution has been found that satisfies the main requirement. In order to get the optimal site (or generation point) set, the above procedure is repeated until Z(S) is minimized. Since the branch and bound algorithm thus developed reduces the number of feasible site (or generation point) sets to be constructed in order to arrive at the optimal solution, great savings are effected as far as time and number of iterations are involved. The details of this method are given in a report prepared by the operations research group [14]. This solution procedure can be easily modified to take care of another type of problem that usually arises; namely one in which some disposal sites are already existing and are operational and only a few additional ones are required. This procedure, given the number of new sites to be opened and where they can be located, leads to the determination of their exact optimal location. A modification to include disposal site capacities can also be incorporated easily. This solution procedure can also be used to optimally locate intermediate points (e.g., treatment plants, transfer stations) once the generation points and disposal sites are given as fixed. However, using it to simultaneously locate disposal sites and intermediate points will not result in an optimal solution.

The application of the procedure described above to the Solid Wastes Management Project is obvious. In any given region there are some existing wastes disposal sites which are currently in operation, as well as other sites which may be potential sites for the future when the existing ones will no longer be available. This argument is valid for the sanitary landfill method of wastes disposal, for incineration, or for any method where future expansion may be required because of limitations in the capacity of an existing facility. The algorithm then can be used to determine where, out of all of the available potential sites, the prescribed number of actual disposal "plants" could be operated in such a manner that the sum of the transportation costs would be at a minimum. The cities, or even smaller subdivisions, if the size of the problem allows it, can be approximated to serve as wastes generation points. So far as the present "state of art" of the procedure is concerned, the actual number of disposal plants to be made operational at the potential sites is left to the user of the program. It is obvious that, as this number is increased, the net transportation costs incurred for wastes disposal will not increase. However, in actual practice, there is a limited budget, and only a given amount of money can be used to acquire the site and get the plant in operation. Thus, a still more global optimum can be obtained by considering the budget restraint. Differing acquisition costs, differing means of wastes disposal leading to a different "payoff" by the site after its usage, as well as several qualitative features which simply cannot be expressed mathematically, certainly add to the complexities of finding a global optimum. For example, a landfill site in general has a short life, but then it may be converted to a golf course, whereas an incineration site has a much longer life but no payoff appeal.

A computer program has been written and will be applied to an existing problem. The nine counties around the Bay Area were chosen as the test area for the study. This region contains 120 cities which served as wastes generation points and 75 wastes disposal sites currently in operation. Another 15 potential sites have been identified by detailed discussions with the authorities concerned. When completed, the program will yield a complete timetable of how much wastes should be disposed of at a given site from a particular city each day; when a given site will be completely used up; which of the potential sites should be made operational and when; and when they should be closed, along with the total optimal operational costs involved (transportation costs plus disposal costs only).

DETERMINATION OF OPTIMAL WASTES FLOW PATTERNS

The principal objective of this aspect of the investigation was to develop a general procedure for shipping wastes from generation points to disposal sites via intermediate points, as required, at minimum costs, and within the limits of transportation and activity capacities. Since the pattern of wastes generation remains essentially the same over short periods of time, the planning horizon encountered here usually is of the order of four to six months.

In the first phase of this investigation, the plan was to examine the specific problem of transporting solid wastes only from communal transfer stations via transfer vehicles. The main characteristic of this type of transportation problem is that the wastes must be shipped in aggregate amounts, such as in large transfer vehicles, and that the aggregate flow not be too small in relation to the total flow leaving the source. In addition, the possible shipping routes from source to sink are constrained for capacity, while the sinks are also capacitated, limiting the aggregate flow into them. Also, since it can be safely assumed that a dump site will always be found to handle the inflow, the feasibility restriction is Σ flows from transfer stations $\leq \Sigma$ disposal capacities, which is the opposite of a regular transshipment feasibility condition. Mathematically, if an artifical source o and sink s be added on, the problem is reduced to:

$$\text{Minimize} \qquad c = \sum_{ij} c_{ij} f_{ij}$$

$$\text{Subject to} \qquad \sum_{j} \left(f_{ij} - f_{ji}\right) = \begin{cases} Q \text{ if } i = o \\ 0 \text{ if } i \neq o,s \\ -Q \text{ if } i = s \end{cases}$$

$$0 \leq f_{ij} \leq k_{ij}$$

and

$$f_{ij} = n\, q_i$$

where n is an integer and q_i is the aggregate flow at source i. An algorithm was developed, which with the proper use of heuristic schemes converges directly on an optimal shipping schedule, and thus eliminates the need of linear programming theory completely. This algorithm provides a framework for partitioning the total problem into subsets, and then guiding the search for a solution along certain of these subsets until the optimal is reached. Applied to the transportation problem, the separation procedure (branching) systematically enumerates the feasible shipping schedules, while the evaluation procedure (bounding) directs the search toward a minimum cost solution. In addition, a heuristic node ordering is utilized to eliminate the examination of uninteresting activities and to facilitate convergence.

In the second phase a model was made of the general problem of transporting and treating all wastes generated in a typical community. The system was then optimized by developing and applying a parametric out-of-kilter linear programming procedure. While the system thus developed was in general a multicommodity network flow problem because of the presence of solid, liquid, and gaseous wastes, the consequent limitations were avoided by incorporating fixed-ratio flow dividers to segregate the commodities and to allow optimization by near-conventional methods. The resulting network is as shown in Figure 1 (see page 53). A few simplifying assumptions were made. These involved either the existence of at least one feasible solution, or the fact that all the wastes generated could be transported, treated, and sent to the final sink. The activity costs were assumed to be linear, and the lower bound on all the arcs to be zero. The treatment plants were represented as fixed-ratio flow separator nodes, with the ratio dependent on each specific plant and fixed over the operation of that plant, but capable of varying from plant to plant. Similar nodal representations were developed for a typical transfer station, solids treatment plant, liquid treatment plant, and the final disposal activity. Mathematically, the problem was reduced to a typical network flow problem with the exception of these fixed flow separator nodes. An algorithm was developed to find the optimal flow through this network. This was done along the lines of the currently popular out-of-kilter algorithm. The flow-labeling rule and the potential change rule which were developed, were quite akin to those already in use in the out-of-kilter algorithm. This algorithm was developed in all its generalities to account for the backtracking of flow, which is usually encountered in such cases. The details of the algorithm are given in a report prepared by the group [14].

OPTIMIZATION OF SOLID WASTES TREATMENT PLANT OPERATION

Introduction

One of the generic components of any solid wastes disposal system – located between the wastes collection activity and final disposal – is the treatment facility. Whether it be of the type that converts wastes into another form such as ash or some valuable resource, that reduces its volume by compaction, or that decomposes its components by separation, the operational structure of the treatment facility is the same. Essentially, one has an arrival stream of raw wastes, a processing or service operation with variable rates, and a storage operation.

Superimposed on this system is a cost structure. If the initial capital cost is fixed, one may wish to examine the day-to-day variable costs in the interest of economy. These daily costs are usually directly proportional to the processing or service rates of the facility. Additionally, if the quantity of raw input wastes temporarily exceeds the quantity of processed wastes, a storage operation becomes necessary. Although, again considering capital costs fixed, the daily cost of storing solid wastes may be negligible, it is still in the interest of public health to keep this quantity of stored wastes at a reasonable level. In more concrete terms, it is advisable to incur a low risk of the delay of any given particle of wastes beyond a specified holding or waiting time.

The manager of a wastes treatment plant is now confronted with an interesting problem, namely: considering the variation in the arrival stream, what service rate policy he should employ to minimize expected processing costs at a given waiting time risk level. The key to the formulation and solution of this problem is to consider an artificial holding or storage cost which is directly proportional to the amount of unprocessed wastes in storage. Once the sum of daily processing and holding costs is minimized with respect to service rate, the resulting waiting time distribution may be related to the artificial holding cost, and optimization for a given risk level may be achieved. It is the first part of this problem that has been currently investigated. More specifically, the problem is: given holding and processing costs, find the service rate rule that minimizes the long-term expected value of the cost rate or gain. Two versions of this problem and their solutions are discussed in the sections that follow. Finally, some extensions to the proposed model are proferred.

Dual Service Rate Treatment Facility with Continuous Arrival of Wastes [1]

General Description. In this version of the problem the treatment facility has two constant processing rates having given operating costs. The arrival of wastes occurs in batches (e.g., truckloads of refuse). Batch amounts have a general (known) distribution and the interarrival times of batches are assumed to be exponentially distributed. Arrival amounts per batch are independent of each other and of the interarrival times of trucks. Both the arrival stream and processing facility are continuously in operation. It is assumed that the holding cost is linear in the current inventory level of wastes.

Assuming that the slower process rate exceeds the mean arrival rate of wastes, a stationary control policy can be found which will minimize the long-run average cost rate. A procedure for optimally operating the facility involves a single critical wastes inventory level above which the fast rate is used, and below which the slower rate is employed.

Mathematical Formulation. The system may be characterized by an underlying continuous parameter, continuous state stochastic process $\{X(t),\ 0 \leq t < \infty\}$, where $X(t)$ is the wastes inventory level at time t in tons. There are two processing rates σ_1 and σ_2 in tons per hours, with respective costs of r_1 and r_2 dollars per hour all considered to be known constants. The holding cost rate at time t is assumed to be $h \cdot X(t)$ dollars per hour, and h is a specified constant. The units for h are in dollars per ton-hour. It is assumed that $\sigma_2 > \sigma_1$, $r_2 > r_1$, and $r_2\ \sigma_1 > r_1\ \sigma_2$. The cost per ton at time t is $(r_1 + h \cdot X(t))/\sigma_1$ and $(r_2 + h \cdot X(t))/\sigma_2$ when rates 1 and 2 are used, respectively.

Batches of material arrive singly in a Poisson process. Let T be the interarrival time with distribution function $F_T(t) = Pr(T \leq t)$, and that $F_T(t) = 1 - e^{-\lambda t}$, for $t \geq 0$, where λ is the average arrival rate in batches per hour and $E(T) = 1/\lambda$. The amount of material in each batch is a continuous random variable and can be specified by any general distribution. Let V be the number of tons making up a batch arrival with distribution function $F_V(\cdot)$. Let $E(V) = 1/\xi$ be the expected number of tons per batch. The average arrival rate is λ/ξ tons per hour. Also, batch sizes are independent of each other and of the interarrival times. Assume that $E(V^2) < \infty$.

If the same processor is always selected whenever a positive amount of material is in inventory, then the process is essentially and M/G/1 queue. Using many well-known properties of M/G/1 queues, the stationary cost rate of the two-processing-rate problem is derived assuming a single inventory level, Y^*, is used as a switchover criterion from rate 1 to rate 2 (Y policy). The optimal π_{Y^*} policy is found in terms of a simple implicit formular for Y^*. It is proven that π_{Y^*} is optimal for all stationary policies.

Continuous-Rate Treatment Facility with Periodic Arrival of Wastes [13,14]

General Description. In this version of the problem, the set of possible deterministic processing rates is extended to a continuum. It is assumed that the processing cost may be approximated by a quadratic in this variable. The arrival stream is interrupted periodically. The distribution of the cumulative quantity of wastes arriving during the "on" portion of each period (equivalent to the eight-hour day of a collection agency) is represented by its first two moments as an approximation, thus allowing a distribution-free analysis. During the "off" portion of the period (equivalent to the remaining 16 hours of a day), no raw wastes are introduced into the system, although the processing facility is allowed to operate for more efficient use of fixed capital outlay. The service rate is selected at the start of the "on" and "off" portions of each period.

The total expected sum of processing and holding costs is minimized with respect to the operating rate. Holding costs are linear in the quantity of wastes present at the end of each period.

Preliminary results indicate that the optimal service rate is linear in the wastes level at the start of each period, and piecewise linear in the quantity of wastes present at the start of the "off" portion of each period. The optimal expected discounted n^{th} period cost is approximated as a quadratic in the wastes level at the start of the n^{th} period.

Mathematical Formulation. The system may be characterized as a continuous state, discrete parameter stochastic process $\{X_i ; i = 1, 2, \ldots\}$, in which X_i represents the amount of wastes in the system at the start of period i. Each period is of length T, and is further divided into two intervals, the "on" interval of length T_1 and the "off" interval of length T_2.

The dynamics of the system state may be understood by examining a realization for a typical period. Figure 1 is a realization for arbritrary period i.

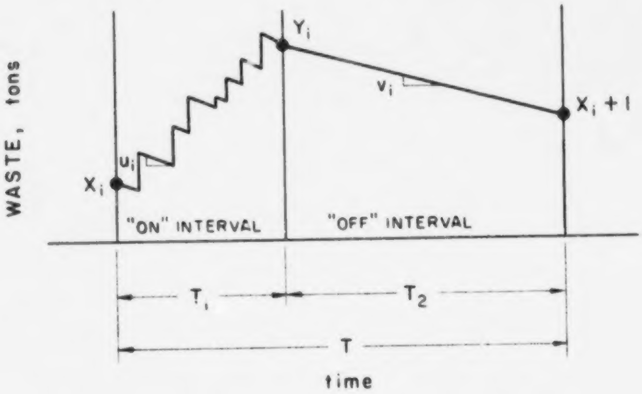

FIGURE I. REALIZATION FOR PERIOD i

It is assumed that the period starts with X_i tons of wastes in the system. During the time T_1 the amount of wastes to arrive in the system is S*, a random variable. The wastes are treated at constant rates u_i (tons/hr) and v_i (tons/hr) during times T_1 and T_2, respectively. It is assumed that the system is highly saturated during the "on" portion of the cycle, so that the amount of wastes, Y_i, remaining in the system at the end of the "on" interval is always positive and is found by the expression $Y_i = X_i + S - u_i T_1$. The amount of wastes, X_{i+1}, remaining at the end of the entire period is either positive or zero, depending on the relative values of Y_i and $v_i T_2$ (the maximum possible amount that can be processed during the "off" interval), i.e.,

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*Items not subscripted with i are the same for all periods.

$$X_{i+1} = \begin{cases} Y_i - v_i\, T_2 & ; \quad \text{if } Y_i > v_i\, T_2 \\ 0 & ; \quad \text{if } Y_i \leq v_i\, T_2 \end{cases} .$$

The single period cost is composed of a holding cost charged at the end of the period and a processing cost charged during the times when the inventory level is positive. The various cost parameters are defined below:

a. Holding costs:

h = unit holding cost in dollars per ton of wastes remaining at the end of the period.

$C_{h,i}$ = total holding cost in period i in dollars.

$$C_{h,i} = \begin{cases} 0 & ; \quad \text{if } X_{i+1} = 0 \\ h \cdot X_{i+1} & ; \quad \text{if } X_{i+1} > 0 \end{cases} .$$

b. Processing costs:

$r(u_i)$ = processing cost using rate u_i charged in dollars per hour during the "on" interval. This is a quadratic convex function in u_i with $r(o) = 0$.

$r(v_i)$ = same as $r(u_i)$ but for the "off" interval.

$C_{p,i}$ = total processing cost in period i in dollars.

$$C_{p,i} = \begin{cases} r(u_i)\cdot T_1 + r(v_i)\cdot Y_i/v_i & ; \quad \text{if } X_{i+1} = 0 \\ r(u_i)\cdot T_1 + r(v_i)\cdot T_2 & ; \quad \text{if } X_{i+1} > 0 \end{cases} .$$

c. Total period costs:

$F_i\,(X_i,u_i,v_i,S)$ = total i^{th} period costs in dollars given the period starts in state X_i with amounts of wastes S arriving during the period and processing rates u_i and v_i being used.

$$F_i\,(X_i,u_i,v_i,S) = C_{h,i} + C_{p,i} \quad .$$

The optimal i^{th} period rates u_i^{o} and v_i^{o} are found by minimizing the above function with respect to the nonnegative variables and u_i and v_i.

$$C_i\,(X_i,u_i^{o},\, v_i^{o}) = \min_{u_i,v_i}\, \{F_i(X_i,u_i,v_i,S)\} \quad .$$

If $C_i\,(X_i,u_i,v_i,S)$ is approximated by a quadratic in Y_i, its expected value may be found in terms of the first two moments of the distribution of S designated as $E\,\{S\}$ and $E\,\{S^2\}$, respectively.

The total expected cost incurred during n consecutive intervals may be found by forming the appropriate recurrence relation and applying Bellman's [16] principle of optimality. The resulting optimal n period policy is denoted as a sequence of rates, $\{u_1^o, v_1^o; u_2^o, v_2^o; \ldots u_i^o, v_i^o, \ldots u_n^o, v_n^o\}$.

Extensions. Work yet to be undertaken in refining the model will be directed to the following objectives:

1. Relate holding cost to waiting time distribution of wastes.
2. Include switchover costs in the cost structure.
3. Investigate nonstationary arrival patterns (seasonality).
4. Include maximum storage and processing capacity for treatment facility.
5. Find optimal plant expansion for a given wastes growth profile.

V. ECONOMICS

INTRODUCTION

Studies of the economic aspects of solid wastes management during the report period were concerned with three principal aspects:

1. The interrelationships of regional economics and the amount of solid wastes generated.

2. Economics of scale in solid wastes management.

3. Economic analysis of technologies under experimental study in the project.

The first of these is an integral part of the planning study and is, therefore, discussed in Chapter III as one of the factors which govern the amount of wastes generated, as well as a possible clue to the wastes which might be expected from any land area planned for a certain pattern of development in the future.

Progress along the second line is one of the subjects reported in this chapter. It concerns evaluation of economics of scale on the basis of data from existing installations.

A report on the third aspect, likewise presented in this chapter, represents the current efforts of the project's economists and technologists to assess the economic feasibility of ongoing technological studies at the present stage of their progress. Two objectives underlie this assessment:

1. An evaluation of the future feasibility of the technologies of composting, anaerobic digestion, biofractionation, wet oxidation, and pyrolysis.

2. On the basis of item 1, either to judge the advisability of continuing research effort along any given line, or to anticipate the amount of work yet to be done before such a judgment is possible.

ECONOMICS OF SCALE

Introduction

Although there are a number of compelling reasons – geographical, jurisdictional, political, and technological – why a regional approach to solid wastes management is logical and necessary, economic factors must weigh heavily in the actual design of any regional system. Particularly important are cost data on the unit processes in the collection-disposal sequence and the way in which economics of scale might be utilized to advantage. However, it is first necessary to determine whether economics of scale do indeed exist in each of the several processes of wastes management.

The discussion which follows is of the nature of a progress report on work by the planning and economics team in collecting and analyzing pertinent data. With respect to the overall mathematical Regional Wastes Generation and Evaluation Model described in the First Progress Report [1] the data sought will serve as input information in the development of the cost row vector representing collection (transportation), treatment, and disposal work (R) in the model, and in arriving at a minimum yearly cost of collecting, treating, and disposing of a set of wastes

(Z^{o} in the model). Since these two factors are essential considerations in the optimization of a disposal program, data related to them serve as input information in the development of the process technology and of the wastes collection, treatment, and disposal submodels.

The specific approach in the economic aspect of the study is to gather and analyze cost data for existing facilities in the real world. Such an approach may not necessarily answer all of the questions relevant to the planning problem, but it does provide a systematic and rigorous framework for determining realistic cost values which must be used in the evaluation of alternatives among wastes management systems. Moreover, because the data used in the analyses pertain to existing facilities operating in the solid wastes industry, they have objective rather than subjective origins.

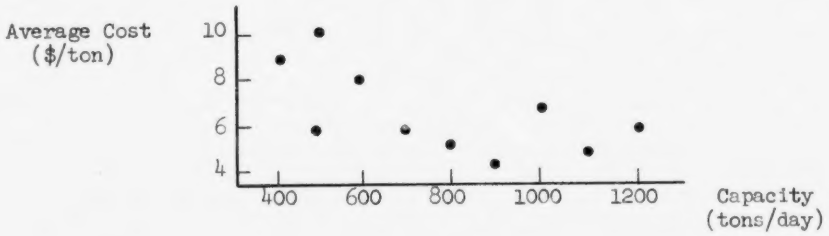
Importance of Economics of Scale

For purposes of the investigation, the term "economics of scale" is defined as the lowering in average cost per unit of wastes processed which accompanies increase in the level of operation (scale) of the plant. Economics of scale is of importance from the standpoint of planning, since one of the major advantages claimed for the regional approach to solid wastes management is that with such an approach large facilities can be used, with consequent superior performance and lower cost than could be done under the present fragmented system. Although there are formidable problems of site and of delivery of wastes which may accompany large-scale disposal undertakings, the first step is to determine the extent of the validity of the foregoing assumption through observations of real situations. It is the objective of the research here reported to undertake this first step.

Analysis of Cost Data

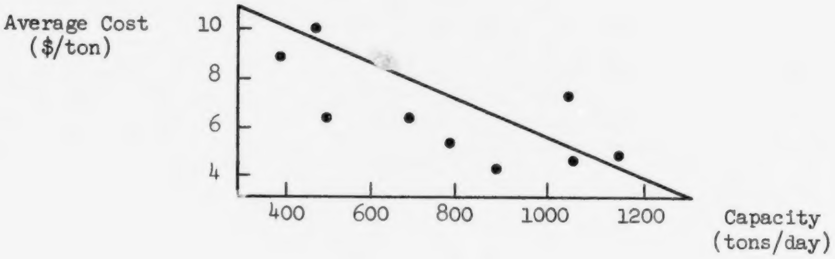
If cost data are to be analyzed to determine whether economies of scale exist in the several processes involved in wastes management, consideration must be given to an appropriate analytical method. To this end the use of regression analysis was proposed as appropriate. In considering how the method might work, the cost of incineration is used as an example. For such a purpose a cost range of $4 to $10 per ton was selected, inasmuch as it is based on a collection of data on a certain number of incinerators. Before starting the analysis, it is determined that the data are comparable, lest the observed differences simply reflect random inclusions and exclusions of categories of cost.

In making the analysis, it is expected or hypothesized that there are some factors which determine a systematic variation in costs. If it is suspected that average cost becomes lower as the capacity of the incinerator increases, the validity of the supposition can be determined by matching cost per ton figures with the capacity figures for each incinerator. In the example, it is assumed that there are 10 incinerators and that the capacity ranges from 400 to 1200 tons per day. The pairing for the 10 incinerators is depicted in the following scatter diagram:



The general trend of the scatter does seem to be lower as capacity increases, but the points do not fall on a straight line or curve. A line, termed a "regression line," may be fitted to the scatter by statistical methods. The line has a general formula for a straight line, namely, $\$/\text{ton} = a_o + a_1$ (tons/day). (For the sake of simplicity, the points were fitted with a straight line. Other functions would have been appropriate.) If it is supposed that the results of the statistical fitting are $a_o = 12$ and $a_1 = -0.008$, the formula becomes \$/ton = \$12 -0.008 (tons/day). The formula allows for the calculation or prediction of average cost in dollars per ton for any value of capacity expressed as tons per day within the cost range of \$4 to \$10 per ton.

Predictions made on the basis of the formula given in the preceding paragraph would not be fully accurate, since the points in the scatter diagram do not all fall on the fitted line. In determining the extent of the error in prediction, reference is made to the following scatter diagram in which the fitted regression line has been drawn:



There is an error in the prediction for each incinerator, the extent of which is measured by the vertical distance between the regression line and the points of the scatter. The regression line is fitted to minimize this error. If, by appropriate tests, the error is proven to be random, then the relation between average cost and capacity has been established except for the unpredictable influence of factors which contribute to the error. If the scatter of points is close to the regression line, the errors in prediction of average cost will be small. A measure of how well the line fits the scatter of data is available from the statistical calculations made in the fitting.

A systematic relation of the errors to the regression line (nonrandom errors) is an indication that some factor, in addition to those plotted in the scatter diagram, also systematically influences cost. In the incinerator plant example, the age of the facility undoubtedly is important. Consequently, age is taken into consideration and is expressed here as (1968-t), in which t is the year during which the plant was constructed. Another axis perpendicular to the two already on the scatter diagram can be constructed for this variable, and the age of each plant can then be matched with its average cost and capacity. A regression plane is fitted to this scatter of points. Its general formula would be: $\$/\text{ton} = a_o + a_1 (\text{tons/day}) + a_2 (1968\text{-t})$. The estimated parameter, a_2, will then express the trend of cost per ton over time independently of the influence of capacity. The underlying cause of the trend may be inflation, or it could be technological change. In the planning problem it would be useful to project this trend into the future to predict incinerator costs.

Other variables may be added to the right-hand side of the cost function. The mathematics of the statistical fitting is complex but rigorous. The interpretations of the estimated coefficients are substantially the same as for the simpler two-variable equation. Parallel tests of the resultant measures are in existence.

Economics of Scale In Collection by Truck

In the determination of the existence and extent of the economies of scale for collection by truck, the following regression equation will be used:

$$P = a_0 + a_1 N + a_2 D$$

in which P is the basic monthly residential charge for service to households; N is the population of the service area; and D is the distance from the center of the collection area to the disposal area.

To treat P (price charged to the household) as a cost, it is necessary to assume the existence of a mechanism, either competition or regulation, through which the price is held at a level close to that of the actual cost. This level should include a normal return on capital. (An inquiry is being made into the price-setting behavior of the individual sample members with the intention of checking the assumption and, if need be, of tempering the conclusions of the regression analysis.) N is a proxy variable for the number of customers, inasmuch as it may or may not be possible to obtain the number cared for by each collection agency. The variable D is included because it exerts a significant influence on the cost of service. Its inclusion will be of assistance in accounting for variances which occur in prices of service.

Data for the regression are available from approximately 73 collection agencies in the nine San Francisco Bay Area counties for the year 1964. At present, monthly residential rates range from $0.75 to $2.50; populations of communities served by the collectors, from 400 to 750,000; and hauling distances, from 0.75 to 21 miles.

If the hypothesis of economies of scale is valid as applied to collection by trucks, the coefficient a_1 should be less than zero. If this should prove to be true, then the obvious conclusion would be that refuse collection agencies should be enlarged to a degree at which the advantages of economies of scale could be attained, other factors permitting. The coefficient a_2 would be greater than zero, since it reflects the increase in costs which accompanies increase in distance of haul. Although unlike coefficient a_1 in its significance in that it does not have a policy implication, it would be useful for making calculations needed in the planning procedure.

In the regression equation formulated in this section, it should be noted that the value for P is not solely that for the price of the collection service; it also includes the cost of disposal. If it is constant or is randomly distributed for the sample, there will be no bias in the estimates of a_1 and a_2. It does seem likely that a systematic relation exists between size of collection agency and disposal cost. If this be true, it will bias the estimate of a_1. The existence of such a relationship will be checked by way of an inquiry into costs at landfills utilized by the collection agencies and by results obtained in research on landfill operating costs.

Incineration

The scale of incineration to be considered in this section is that characteristic of incineration on a municipal or regional basis. A scale of this magnitude was chosen because of its bearing on air pollution control. It is only when practiced on such a scale that satisfactory air pollution control can be carried on within a cost range meriting consideration. Unless equipped with expensive control equipment, "teepee burners" and incinerators on the scale used in "backyard" burning will necessarily be sources of severe air pollution. Consequently, incineration of the magnitude characteristic of the latter types of units is not considered in this investigation.

In the study reported herein, the plan is to collect data on a sample of incinerators with respect to initial capital costs and to operating costs incurred over a period of one year. Variations in the average costs as determined from the collected data will be analyzed by the regression technique. The cost per ton value will be taken as equivalent to the long-run average cost in economic theory in which all inputs are variable, and the cost per ton is a minimum for the scale of operation. In analyzing data pertaining to capital costs, a separation will be made between cost of the land on which a plant is built and the other elements making up its capital costs. The separation is made because costs associated with the incinerator plant itself are functions of plant size, whereas those concerned with land are functions of the land value in the region in which the plant is built, and thus are more or less independent of plant size. Hence, the location should be analyzed separately.

The average cost for the year of operation selected for study will be the sum of two items:

1. The dollar equivalent in capital for the year, and
2. Operating and maintenance costs for the year in terms of dollars per ton.

Item 1 is obtained by dividing the capital costs of the plant and equipment (excluding air pollution equipment) by the number of years in the life span of the equipment. An attempt will be made to separate costs associated with air pollution control from those for incineration itself, so that the capital involved in the air control equipment can be related to the efficiency of air pollution control equipment and the scale of the incineration operation.

Item 2 is obtained by dividing the total operating and maintenance costs for the year by the number of tons of wastes incinerated (i.e., input of wastes minus residue) during that time.

In addition to the important question of economies of scale in incineration, is the one of whether or not technical advances made in incineration practice have contributed to a lowering of the per-ton cost of the process. An approach to answering the two questions can be made by use of the regression equation,

$$C = a_0 + a_1 S + a_2 (1968-t)$$

in which C is the average cost in dollars per ton of wastes destroyed, as defined previously; S is the number of tons of wastes destroyed during the year in question; and (1968-t) is the age of the capital equipment. If the coefficient a_1 is negative, economies of scale exist. If a_2 is positive, technical change is demonstrated to have contributed to a reduction in the per-ton cost of incineration. (All cost elements will be deflated according to a price index so as to remove the effect of inflation over time.)

Inasmuch as they are in the process of being collected, data to be used in the analysis of incineration costs have only been partially organized thus far. At present, the collection of data on hand consists of information on various categories of costs in varying amounts of detail for approximately 150 incinerators. A goodly portion of the data cannot be utilized because of their doubtful reliability, and many of them are inadequate as far as analysis is concerned. Probably, data can be obtained from a sample of from 30 to 50 incineration facilities constructed since 1960 which will be suitable for the study.

Transfer and Long-Haul Transport In Road Vehicles

An activity which is coming into increasing use in solid wastes management as landfill sites become more distant from the wastes sources is the transfer of refuse from the collection truck to a long-haul truck by way of appropriately located transfer stations. Generally, a collection vehicle is very costly to use for the straight-haul portion of the wastes handling sequence, since it has a relatively small capacity and carries a crew of from two to four men. The unit is designed for performing an efficient job of collecting refuse in residential areas, and as such is not geared to the efficient transfer of the wastes over long distances. On the other hand, the tractor-trailer rig, because of its large capacity and need for only a one-man crew (the driver) can be used for long hauls at a lower unit cost than would be the case with the collection truck.

Although transfer-transport usually is associated with landfill disposal, it can be used just as well in connection with other disposal or treatment systems. Thus, transfer-transport may be an input between collection and any method of final disposal in a wastes management system.

The costs to be investigated with respect to transfer and long haul are the capital costs of the transfer station (exclusive of land) and road vehicles, on the costs of operating the facility and equipment. Transfer stations vary quite broadly in terms of components. A common characteristic is an arrangement of ramps whereby collection trucks can be unloaded and their contents transferred to road trailers. The transfer station may include equipment for weighing, storing, and compacting wastes. The operation may or may not be housed. Trailers used in the operation are of the type especially designed for the bulk hauling of materials of low densities.

The regression equation to be used in the investigation of the average cost function of the transfer—long haul operation is

$$C = a_0 + a_1S + a_2D$$

in which C is the average cost of transfer and haul in dollars per ton. It is the sum of the capital costs of the station and road equipment prorated for the year in question and the total of the year's operating costs of the station, and the road equipment divided by the number of tons handled during that time. S is the number of tons of wastes handled during the year. D is the number of miles traveled during the year by the road vehicles.

Cost per ton is the dependent variable on the left side of the equation to be estimated, rather than cost per ton-mile as is usually reported. This specification is made because the effects of variation in tons and miles on costs are presumed to differ. Separation of these effects could not be done by using a specification of cost per ton-mile.

If economies of scale are present, the coefficients a_1 and a_2 will be negative.

The data for this investigation as yet have not been fully organized. Again, partial data have been obtained for a number of cases, and a reference file of approximately 40 transfer-transport operations has been obtained. The extent of the response to the questionnaire to be sent to these operations will determine the final size of the sample.

Landfill Utilization

Although landfill as a method of wastes disposal may be the simplest from the technological point of view, it does present rather substantial difficulties in terms of economic analysis. Any meaningful analysis will be somewhat limited in the scope of its application, since much of the cost of the operation is related to that concerned with the site of the operation. By the very nature of the operation, three major items determine the per-ton cost of disposal by landfill. They are: 1) cost of the site itself; 2) the topography of the site; and 3) the yearly input or scale at which the landfill is operated. The first item or determinant cannot be analyzed in a meaningful way on the basis of data from a survey of existing sites, since the price of land is a specific which varies from region to region. For example, the knowledge that land values are high in the vicinity of New York City has little application to planning for wastes disposal by landfill in northern California. Because of extreme variability, the use of information on land values could only lead to trivial analysis, and therefore this quantitatively important variable is left out of the analysis.

Although the second variable, topography of the site, will be analyzed statistically, the analysis will not be wholly satisfactory because of the qualitative nature of the variable. A casual inspection of data on tons of wastes per acre at landfill sites gives one the impression that dry flatlands are at the low end of the scale and canyons are at the high end. The research plan calls for quantifying the relation between tons per acre (density) and topography by regression analysis of density on an ordinal ranking of topography type assigned to each landfill. The ranking will be 1) dry flatlands; 2) tidelands; and 3) canyons. The ranking involves some judgment and the assignment of some ordinal value to somewhat dissimilar elements. As a result, the statistical technique will treat the ordinal values as though they were cardinal values. Useful information can come out of the analysis, however.

The equation to be estimated is

$$D = a_0 + a_1 T$$

in which D and T are respectively, density and topography, as defined above. The estimated coefficient a_1 will supply a quantitative measure of the change in technological efficiency for receipt of solid wastes as topography changes. The variance of the estimate of a_1 is expected to be high because of the qualitative nature of the variable.

The final question is whether economies of scale exist for landfill operations with respect to the elements of cost, exclusive of land costs. These cost elements are termed variable costs and include all site modifications, structures, equipment, and operating costs. Some of these elements of cost are long-lived, and, consequently, a share of them must be assigned for the year of operation being studied. This is the same situation which exists for incineration and transfer-transport, and it will be handled in the same way.

To control the effect on cost of topography, each of the variables will be subject to a separate regression analysis. The equation to be estimated is

$$C_1 = a_0 + a_1 S \quad : \quad 0 = 1, 2, 3 \text{ (topographical type)}$$

in which C_1 is the average cost; namely, the prorated capital costs for the year plus the operating costs for that year divided by the year's input of wastes, S. If economies of scale are present for variable costs, a_1 will be negative.

The data for the regression analysis of the relation between density and topographical type have been supplied by the Association of Bay Area Governments and the California State Department of Public Health, Vector Control Division. It consists of a tabulation of 1) the total area of each site; 2) the unusable area remaining; 3) the depth of the fill; and 4) an estimate of the weight of refuse received per year.

The data for operating costs will be obtained by way of a questionnaire sent to a sample of approximately 15 public agencies in California that operate about 50 sanitary landfills. Those agencies were selected which maintain good control over type of wastes received and which hold to high aesthetic and sanitary standards of operation. The sampling was restricted to facilities operating under these high standards, because standards of this level will be the only ones permissible in the management of wastes in the future.

Discussion

Although the methodology herein described seems appropriate to the planning and economics objectives of the study, it is not as yet clear whether sufficient data from the real world can be assembled. An analysis of such data resulting from various national, regional, and local surveys indicates that generally the objectives of the surveys are too broad for the scale of their budget. The result is that the detail needed for economic analysis, or even for classification of the wastes at levels below general categories, is either not obtained or not reported. Further complications exist in the way cities keep their records. Often it is impossible to determine what fraction of the salaries of engineers, public works directors, payroll and clerical staffs, etc., is applicable to one utility as against another, even though data on the number of men employed in various phases of the solid wastes management process are readily available. Furthermore, there is no easy way of comparing one incinerator, for example, with another in terms of efficiency of operating personnel or of bringing the cost of incinerators built over a period of years to some common basis. Nevertheless, some data do exist and, as noted in previous sections, may contribute significantly to the economic study under way.

ECONOMICS OF THE LOW-COST BIOSTABILIZATION (COMPOSTING) SYSTEM

Background

The Process. The low-cost method of biostabilization considered in this analysis is described in Chapter V of this report. It involves three principal processing steps: grinding, composting, and incorporation of the material into the soil. The degree of processing applied in the composting step is intended to be minimal. In fact, as stated previously, a study is being made of the possibility of omitting the composting step and of incorporating the material into the soil directly after grinding without giving rise to any nuisances or environmental hazards.

Land Requirement. Since an essential feature of the system involves tilling processed wastes into the soil, land requirements are a major consideration in making an analysis of the economics of the system.

The method probably would be most appropriate to a city of 25,000 to 250,000 people. In the analysis which follows, a city of 100,000 people is assumed. At present levels the inhabitants of this city would produce about 3.0 pounds per capita per day of domestic plus biodegradable commercial solid wastes. The annual wastes production amenable to the low-cost compost system of management thus would be

$$100{,}000 \text{ people} \times \frac{3.0 \text{ lb}}{\text{capita-day}} \times \frac{\text{tons}}{2000 \text{ lb}} \times \frac{365 \text{ days}}{\text{year}} = 54{,}750 \frac{\text{tons}}{\text{year}} \quad .$$

If refuse can be applied to the land at 200 tons per acre-year as now seems feasible, the land requirement would be

$$54{,}750 \frac{\text{tons}}{\text{year}} \div 200 \frac{\text{tons}}{\text{acre-year}} = 276.5 \text{ acres, i.e., about 280 acres} \quad .$$

Total Daily Production. Refuse is generally collected and disposed of 5 days per week, or 260 days per year, therefore the daily amount to be handled would be

$$54{,}750 \frac{\text{tons}}{\text{year}} \div 260 \frac{\text{working days}}{\text{year}} = 204.2 \text{ tons per day} \quad .$$

Typically, Mondays and Tuesdays are "heavy" days and the collection may be 200 tons per day or more, with lighter loads during the latter part of the week. Although the operation probably should be designed to handle 250 tons per day, the calculations given below are based upon the average, or 205 tons per working day.

Costs

Hauling. Although hauling generally is not considered in making an economic analysis of a particular disposal method, attention is given to it in this analysis, inasmuch as in practice the system would involve fairly long hauls. It is quite likely that the site would have to be some 15 to 20 miles from the city center. Therefore, the first charge would be to refuse hauling, namely,

$$205 \frac{\text{tons}}{\text{day}} \times 20 \text{ miles} \times \frac{\$0.08}{\text{ton-mile}} = \$328.00 \quad .$$

Refuse Grinding. Preliminary figures based on data obtained in refuse grinding cost studies being conducted at the city of Madison, Wisconsin, under a U. S. Public Health Service demonstration grant suggest that grinding for the low-cost compost system may cost about $2.60 per ton.

$$205 \frac{\text{tons}}{\text{day}} \times \frac{\$2.60}{\text{ton}} = \$533.00 \quad .$$

Composting. To produce a compost of a grade acceptable to agricultural or nursery usage, an expenditure of $5.00 to $13.00 per ton of raw refuse is necessary. The Metropolitan Waste Conversion composting plant at Gainesville, Florida, for example, expects to perform salvage plus composting to make a top-quality compost for $6.53 per ton of raw refuse. The minimal composting-without-quality-upgrading called for in the low-cost composting system will, hopefully, cost only $1.50 per ton.

Thus, the cost of composting the refuse from the city of 100,000 would be:

$$205 \frac{\text{tons}}{\text{day}} \times \frac{\$1.50}{\text{ton}} = \$307.50 \quad .$$

Field Spreading and Tilling. The ground refuse or rough-quality compost must be transported from the processing plant to the "disposal" area, spread out, and tilled in. If the processing plant is adjacent to the farm, two dump trucks of 5-ton (25 cu yd) capacity could easily transport 205 tons 1/2 or 1 mile. Such dump trucks, with drivers, might cost

$75 per day each = $150.00 .

The 205 tons per day will be put on at 200 tons per acre; therefore, 205 tons per day ÷ 200 tons per acre = 1.0 acre will be "farmed" each day. To distribute the dump truck loads of refuse onto the land and till it in, a medium-sized (50 hp) crawler tractor with dozer blade and plow will be required. Although the actual distribution and spreading should take only two or three hours per day, the daily charge would approach that of full-time tractor rental, ($75 per day), so a $60 per day charge is assumed.

The acre that receives the 205 tons on one day will not be ready to accept another 205 tons until the same day one year hence. In the intervening year it will probably be necessary to irrigate three times ($20 per acre-irrigation, for water plus labor), plow or disc once to encourage biological breakdown ($15 per acre), and fertilize to obtain a better nutrient balance (estimate 300 lb nitrogen at 6¢ per lb = $18.00 plus application cost of $10 per acre). The total cost of irrigation and fertilization, therefore, would be $103 per acre.

The total cost of the field spreading and tilling step, therefore, would be $313.00.

Land-Use Charges. It would be hoped that the site of the facility, some 20 miles from the city center, would be on poor land obtained at minimal price. However, it is likely that political pressures would drive the land cost quite high, and consequently a land-use cost must be included. Assuming $1000 per acre land with a 20-year salvage value of $500 per acre instead of a normal appreciation to $2000 per acre, it would mean a land-use charge of:

(1.00 acre) ($1500 value loss) (capital recovery at 8% – 20 years)
+ (1.00 acre) ($500 tied up) (8% interest) = $188.00 .

A private entrepreneur would have to pay property taxes on the land, while a municipal operation would lose tax revenue by operating the garbage farm. Thus, if annual taxes are assumed to be 3% of the $1000 land investment, the tax would be

$$(.03) \left(\frac{\$1000}{\text{acre}} \right) \times (1.0 \text{ acre}) = \$30.00 \quad .$$

The total cost for land use, therefore, would be $218.00.

Burial of Noncompostables. Although the low-cost method of biostabilization would be expected to care for the normal garbage and domestic refuse, it probably will be uneconomical to shred tires, bedsprings, tree stumps, overstuffed furniture, concrete rubble, and similar materials. These might average 5 percent of the 205 tons per day, or 11 tons per day. The cost of hauling this to the inevitable burial site, and burying it, might amount to $4.00 per ton = $44.00.

Summary of Costs. Total costs, including actual composting:

(328 + 533 + 308 + 313 + 218 + 44) = $1744 per day

Excluding the composting ($1744 - 308) = $1436 per day

Cost per ton is $1744 per day
÷ 205 tons per day = $8.50 per ton raw refuse

and $1265 per day
÷ 205 tons per day = $7.00 per ton raw refuse

Cost per person-year = $1744 per day
x 260 working days per year
÷ 100,000 persons = $4.53 per person-year

$1436 per day
x 260 working days per year
÷ 100,000 persons = $3.73 per person-year

Comparison with Conventional Composting Methods

These prices (of $7.00 per ton, or $8.50 per ton depending upon the need to compost or not) seem very high. They seem even higher when one quotes $1.50 per ton for landfilling (without considering hauling), $6.52 per ton for composting as is hoped for at Gainesville, Florida, or the typically quoted $6.00 per ton for incineration. It is felt that the hypothesized low-cost biostabilization figures are on the very conservative side, while the alternative method figures may not be quite so conservative. For example, in estimating land-use charges, it is assumed that the land used in the operation will depreciate in monetary value over the years, whereas, judging from the present escalation in land values, the odds are equally in favor of the land retaining its present monetary value or even acquiring a higher value. For instance, the $1.50 per ton sanitary landfill cost is actually attained in Los Angeles, but 8,000 to 10,000 tons per day are handled, and the economy of scale is important. Additionally, the transportation cost of perhaps $0.08 per ton-mile x 20 to 25 miles is not included. Certainly, for comparison, a hauling distance at least equal to that used in this analysis should be used.

The Gainesville composting cost estimate of $6.52 per ton of raw refuse would be more desirable than the costs given for the low-cost composting system. In fact, if Gainesville could sell the compost, the net cost per ton raw refuse would be further reduced. If the city could merely give the compost away, the cost would be the quoted $6.52 per ton. But if the city cannot sell or give the compost away it might have to bury it, and this would add to the cost.

Likewise, the quoted figures for incineration are subject to enquiry regarding plant amortization period, interest rate, and whether ash disposal costs are included.

From the foregoing considerations it is concluded at this time that, even with very conservative cost estimating, low-cost composting appears to be comparable to other wastes processing-discharge methods, and to be worth further consideration.

ECONOMICS OF THE ANAEROBIC DIGESTION PROCESS

Introduction

The factors which determine the economic advantage or disadvantage in utilizing conventional anaerobic digestion for the treatment ("disposal") of organic solid wastes such as garbage, rubbish, and wastepaper are so dependent on local conditions that no general conclusions can be reached which would be valid for all circumstances. However, judging from the experience of the many municipalities in the U. S. which are practicing in varying degrees the dual disposal of the sewage sludge and the garbage fraction of refuse, the process apparently should be reasonable in cost.

The economic analysis made herein includes the costs entailed in the establishment of the central grinding stations needed in those operations in which all of the organic refuse is to be digested, i.e., that fraction not ordinarily ground into the sewer by way of the home garbage grinder. In the analysis, a complete breakdown of costs ascribed to each step in the process (grinding, grit removal, digestion, etc.) is given for cities of small, intermediate and large-sized populations. The analysis is divided into two parts. In the first part, treatment of all of the organic constituents of refuse is considered; in the second part, the garbage fraction only.

Assumptions

In making the analysis, the following assumptions are made:

1. Population

City A	30,000	(small city)
City B	300,000	(medium city)
City C	1,000,000	(large city)

2. Domestic refuse to be treated (includes garbage):

   3.0 lb per capita per day [17].

3. Garbage to be treated (includes a portion of wasted wrapping paper):

   0.45 lb per capita per day (15 percent of total domestic refuse [17].

4. The wastes have been collected and transported to the central grinding station.

5. The wastes are treated as follows:

   a. The wastes are weighed and then dumped into a hopper.

   b. A conveyer belt transports the wastes from the hopper to a primary grinder in which the packages are shredded and their contents exposed.

   c. Another conveyer belt transfers the shredded material to a third belt which serves as a "sorting" belt. Here salvageable items and oversized material are removed. A magnetic separator is used for removing ferrous materials.

   d. The sorted wastes are then subjected to a secondary grinding.

   e. A grit chamber receives the final ground garbage and a pump transports the grit-free ground wastes to an anaerobic digester.

   f. Digested wastes are pumped to a drying bed.

g. Dried digested wastes either are ready to be composted or to be combined with sorted refuse (other than the salvaged portion) for incineration or landfill.

6. A separate digester is required for handling the additional solids.

Amounts of Wastes to be Treated

Total Domestic Refuse:

3.0 lb/capita/day x 30,000 = 90,000 lb/day (45 tons) – City A
3.0 lb/capita/day x 300,000 = 900,000 lb/day (450 tons) – City B
3.0 lb/capita/day x 1,000,000 = 3,000,000 lb/day (1,500 tons) – City C

Garbage Only (15 percent of Refuse):

13,500 lb/day (6.75 tons) – City A
135,000 lb/day (67.5 tons) – City B
450,000 lb/day (225 tons) – City C

Grinding

The data on grinding are based on those in a recent publication of the American Public Works Association [17].

For a grinding plant of 300 tons per day capacity and which includes an enclosed dumping area, primary and secondary grinders, conveyors, standby equipment, air purification equipment, employees' facilities, etc., the plant building would cost $300,000; and the plant equipment, $300,000. Assuming a 30-year life span for the building, construction costs would be $0.40 per ton of wastes. Assuming a 20-year life span for the equipment, operation and maintenace costs should be on the order of $0.50 to $1.00 per ton.

To accommodate the three population sizes used in the analysis, an interpolation was made in determining the costs for each population size. The interpolation was based on information contained in the U. S. Public Health Service publication No. 1229 [18]; according to which, the ratio of costs per capita for the construction of primary treatment and separate sludge digestion plants between populations of 1000, 10,000, and 100,000 is on the order of 4:2:1. In the present analysis, it is assumed that this ratio also holds true for the population sizes 30,000, 300,000, and 1,000,000.

By proportion, the grinding costs for City A would be $3.00 per ton x 45 or $135 per day, if all of the domestic refuse were ground. If only the garbage is to be treated, grinding costs would be $6.00 x 6.75 or $40.5 per day. (It is assumed that it would cost twice as much to grind garbage alone.) The costs for City B would be $1.60 per ton x 450 or $720 per day for the refuse; and $3.201 per ton x 67.5 or $216 per day if only the garbage is ground. The costs for City C would be $0.80 per ton x 1500 or $1200 per day for refuse; and $1.60 x 225 or $360 per day if only the garbage is ground.

The grinding costs may be summarized as follows:

City A a. $135/day = $ 49,250/yr = $1.64133/capita/yr
b. $40.5/day = $ 14,800/yr = $0.4933 /capita/yr

City B a. $720/day = $262,500/yr = $0.87500/capita/yr
b. $216/day = $ 78,800/yr = $0.26267/capita/yr

City C a. $1200/day = $438,000/yr = $0.43800/capita/yr
b. $360/day = $131,250/yr = $0.13125/capita/yr

Digestion

Volumes. If the daily flow rate to the digester is assumed to be two gallons per pound of refuse or garbage ground [17], then the following would apply:

City A:

a. If refuse is disposed of:

2 gal/lb x 90,000 lb/day = 180,000 gal/day = 0.18 mgd

b. If garbage only is treated:

2 gal/lb x 13,500 lb/day = 27,000 gal/day = 0.027 mgd

City B:

a. If refuse is disposed of:

2 gal/lb x 900,000 lb/day = 1,800,000 gal/day = 1.8 mgd

b. If garbage only is treated:

2 gal/lb x 135,000 lb/day = 270,000 gal/day = 0.27 mgd

City C:

a. If refuse is disposed of:

2 gal/lb x 3,000,000 lb/day = 6,000,000 gal/day = 6.0 mgd

b. If garbage only is treated:

2 gal/lb x 450,000 lb/day = 900,000 gal/day = 0.9 mgd

Digester Costs. According to the sludge handling cost curve for standard-rate filtration developed by Logan et al. [19], the construction cost would be 1/5 of the total cost, which includes chlorination, pumping, and administration fees. The same would be true for operation costs. Using the cost curves by Logan et al., the following calculation may be made if a construction life of 20 years and a capital interest of 4 percent are assumed:

City A:

a. If refuse is disposed of:

Construction cost:

5 x \$115,000/mgd x 0.18 mgd = \$103,500

$$\frac{\$103{,}500\ (1 + 0.04)^{20}}{20 \times 30{,}000} = \$0.37750/\text{capita/yr}$$

Operation cost:

5 x \$5,000/mgd x 0.18 mgd = \$4500/yr

$$\frac{\$4500/\text{yr}}{30{,}000} = \$0.15/\text{capita/yr}$$

b. If garbage only is treated:

Construction cost:

5 x \$140,000/mgd x 0.027 mgd = \$18,925

$$\frac{\$18,925\ (1 + 0.04)^{20}}{20 \times 30,000} = \$0.06900/\text{capita/yr}$$

Operation cost:

5 x \$6500/mgd x 0.027 mgd = \$877.5/yr

$$\frac{\$877.5/\text{yr}}{30,000} = \$0.02925/\text{capita/yr}$$

City B:

a. If refuse is disposed of:

Construction cost:

5 x \$85,000/mgd x 1.8 mgd = \$765,000

$$\frac{\$765,000\ (1 + 0.04)^{20}}{20 \times 300,000} = \$0.27950/\text{capita/yr}$$

Operation cost:

5 x \$3500/mgd x 1.8 mgd = \$31,500/yr

$$\frac{\$31,500/\text{yr}}{300,000} = \$0.10500/\text{capita/yr}$$

b. If garbage only is treated:

Construction cost:

5 x \$105,000/mgd x 0.27 mgd = \$141,750

$$\frac{\$141,750\ (1 + 0.04)^{20}}{20 \times 300,000} = \$0.05175/\text{capita/yr}$$

Operation cost:

5 x \$4500/mgd x 0.27 mgd = \$6075/yr

$$\frac{\$6075/\text{yr}}{300,000} = \$0.02025/\text{capita/yr}$$

City C:

a. If refuse is disposed of:

Construction cost:

$5 \times \$72{,}000/\text{mgd} \times 6.0 \text{ mgd} = \$2{,}160{,}000$

$$\frac{\$2{,}160{,}000\ (1 + 0.04)^{20}}{20 \times 1{,}000{,}000} = \$0.23700/\text{capita/yr}$$

Operation cost:

$5 \times \$3000/\text{mgd} \times 6.0 \text{ mgd} = \$90{,}000/\text{yr}$

$$\frac{\$90{,}000/\text{yr}}{1{,}000{,}000} = \$0.09000/\text{capita/yr}$$

b. If garbage only is disposed of:

Construction cost:

$5 \times \$90{,}000/\text{mgd} \times 0.90 \text{ mgd} = \$405{,}000$

$$\frac{\$405{,}000\ (1 + 0.04)^{20}}{20 \times 1{,}000{,}000} = \$0.04435/\text{capita/yr}$$

Operation cost:

$5 \times \$3700/\text{mgd} \times 0.90 \text{ mgd} = \$16{,}650/\text{yr}$

$$\frac{\$16{,}650/\text{yr}}{1{,}000{,}000} = \$0.01665/\text{capita/yr}$$

The summary of construction and operation costs of anaerobic digestion facilities is as follows:

City A	a.	$0.52750
	b.	$0.09825
City B	a.	$0.38450
	b.	$0.07200
City C	a.	$0.32700
	b.	$0.06100

Maintenance and Miscellaneous Costs. According to Logan *et al.* [19], costs for maintenance and repairs, materials, supplies, and miscellaneous should average $2000 per year per mgd plant capacity. Based on this given data, the cost calculation may be made as follows:

City A:

a. If refuse is disposed of:

$$\frac{\$2000/\text{yr}/\text{mgd} \times 0.18\ \text{mgd}}{30{,}000} = \$0.01200/\text{capita}/\text{yr}$$

b. If garbage only is treated:

$$\frac{\$2000/\text{yr}/\text{mgd} \times 0.027\ \text{mgd}}{30{,}000} = \$0.00180/\text{capita}/\text{yr}$$

City B:

a. If refuse is treated:

$$\frac{\$2000/\text{yr}/\text{mgd} \times 1.8\ \text{mgd}}{300{,}000} = \$0.01200/\text{capita}/\text{yr}$$

b. If garbage only is treated:

$$\frac{\$2000/\text{yr}/\text{mgd} \times 0.27\ \text{mgd}}{300{,}000} = \$0.0180/\text{capita}/\text{yr}$$

City C:

a. If refuse is treated:

$$\frac{\$2000/\text{yr}/\text{mgd} \times 60\ \text{mgd}}{1{,}000{,}000} = \$0.1200/\text{capita}/\text{yr}$$

b. If garbage only is treated:

$$\frac{\$2000/\text{yr}/\text{mgd} \times 0.90\ \text{mgd}}{1{,}000{,}000} = \$0.00180/\text{capita}/\text{yr}$$

Cash Value of Digester Gas

Volume of Gas Produced. In conventional raw sewage sludge digestion, about 12.5 cu ft of gas are produced per pound of volatile solids destroyed. The volatile solids destruction is about 63 percent. When garbage is digested, the gas produced per pound of volatile solids introduced would be 7.9 cu ft per pound [1]. Judging from experience gained in the study reported herein, the amount of gas which would be produced in the digestion of refuse would be one-half (3.95 lb per cu ft) that from the digestion of garbage alone.

Assuming that the volatile solids content in garbage is 75 percent and in refuse 45 percent [1,17], and that the per capita production of refuse and of garbage is 3.0 and 0.45 pounds per day, respectively, then the following calculations are applicable:

Gas Production:

a. If refuse is treated:

$$7.9\ \text{cu ft/lb VS} \times 0.50\ (\text{VS content}) \times 3.0 \times 0.45 = 5.33\ \text{cu ft/capita/day}$$

b. If garbage only is treated:

$$7.9 \text{ cu ft/lb VS} \times 0.45 \times 0.75 = 2.67 \text{ cu ft/capita/day}$$

Sale of the Gas. The Pacific Gas and Electric Company sells gas for $0.08 per 100 cu ft. Inasmuch as gas produced from the digestion of sewage sludge contains an average of 30 percent CO_2, an optimistic estimate of the sales price of the digester gas would be about $0.05 per 100 cu ft. According to calculations based on a sales price of $0.05 per 100 cu ft, the sales value of the digester gas would be:

a. $0.05/100 cu ft x 5.33 (cu ft/capita/day) x 365 = $0.974/capita/yr .

b. If garbage only were treated:

$0.05/100 cu ft x 2.67 x 365 = $0.487/capita/yr

Summary of Costs

The costs involved in treating domestic refuse by way of conventional anaerobic digestion are summarized in Table 17 and 18.

Discussion

In studying the cost data given in the preceding paragraphs, certain of the assumptions listed in the section "Assumptions" should be emphasized, namely:

a. The digester gas can be sold at the rate of $0.05 per 100 cu ft.

b. The refuse has been collected and transported to the grinding station. In other words, these costs are not included in the calculations.

c. No increase in primary treatment capacity would be required.

The first of the above three assumptions led to the conclusion that the cost of treatment could be offset by $0.50 to $1.00 per capita per year. Although the last three columns in Tables 17 and 18 indicate that a profit could be made by digesting domestic refuse and selling the digester gas, it is unlikely that such a highly favorable event would ever come to pass. The cash values given for the gas do not include the cost of processing, transporting, and metering the gas. More importantly, before a profit can be realized, a market must be found for the gas. In areas where natural gas is in abundant supply, this may be difficult to do. However, in the long run, the day may come when all energy sources must be exploited to their full potential.

With respect to the second assumption, it should be kept in mind that these costs would be incurred regardless of the method of treatment or disposal to be given the refuse. According to a report prepared by Ross [20], the cost of collection in 1960 in Richmond (population 50,000), Indiana, was $11.30 per ton of garbage.

The basis of the third assumption is the fact that the increase in flow rate in the sewers needed to accommodate the refuse loading would only be on the order of 6 percent.

The digester volume required to treat a given amount of refuse solids is much less than that required for an equal amount of sewage sludge. The reason is that it is possible to thicken the refuse "sludge" to 10 percent; whereas sewage

TABLE 17

COST PER CAPITA PER YEAR FOR DIGESTING REFUSE[a]

Items	City A 30,000 Population		City B 300,000 Population		City C 1,000,000 Population	
	Refuse	Garbage	Refuse	Garbage	Refuse	Garbage
Grinding Process	1.64133	0.49333	0.87500	0.26267	0.43800	0.13125
Anaerobic Digestion	0.52750	0.09825	0.38450	0.07200	0.32700	0.06100
Maintenance and Miscellaneous	0.01200	0.00180	0.01200	0.00180	0.01200	0.00180
Total Costs	2.18083	0.59338	1.27150	0.33647	0.77700	0.19405
Cash Value of[b] Digester Gas	0.974	0.487	0.974	0.487	0.974	0.478
Net Costs	1.10683	0.10638	0.29750	-0.15053	-0.19700	-0.28395

[a] Based on the value of the dollar in 1960

[b] F.O.B. the treatment plant

TABLE 18

COST PER TON OF REFUSE OR GARBAGE DIGESTED[a]

Items	City A 30,000 Population		City B 300,000 Population		City C 1,000,000 Population	
	Refuse	Garbage	Refuse	Garbage	Refuse	Garbage
Total Costs	4.00	7.24	2.32	4.10	1.42	2.37
Cash Value of[b] Digester Gas	1.78	5.93	1.78	5.93	1.78	5.93
Net Costs	2.22	1.31	0.54	-1.83	-0.36	-3.56

[a] Based on the value of the dollar in 1960

[b] F.O.B. the treatment plant

sludge generally is pumped to the digester at a concentration of 4 to 6 percent. Moreover, the concentration of a slurry of solid wastes is easily adjusted. Sewage sludge, on the other hand, generally has to be thickened by way of expensive physical and chemical processes. The calculations presented in this report are based on the use of a 6 percent slurry. According to Torpey and Melbinger [21], however, the digester of slurries having concentrations higher than 6 percent would give rise to no operational problems. Loadings administered in the experiments reported herein were made at slurry concentrations conventionally applied. The research plan calls for future research on the effect of loadings at higher solids concentrations in the slurry.

Conclusions

Although the various assumptions and estimates noted in the preceding paragraphs may be of debatable accuracy, the indications are that digestion of organic refuse with sewage sludge cannot be ruled out on economic grounds, insofar as the digestion process itself is concerned. A complete economic analysis leading to a judgment of what fraction of the overall organic wastes of a community could be assembled and digested economically is, of course, beyond the scope of this report.

ECONOMICS OF BIOFRACTIONATION

Preliminary Cost Estimate of the Proposed Microbial Cellulose Decomposition Process

In order to determine in a very general way the economic feasibility of a process to convert paper wastes to protein and glucose, a cost estimate study was made for the process diagrammed in Figure 33 (see Chapter XI,. The estimate is based on data for decomposition and hydrolysis rates reported for S. myxococcoides [21]. The cost estimate is very preliminary in nature, since the basic data are few and many assumptions concerning process conditions, yields, and equipment performance were necessary. The following evaluation was developed according to a method outlined by Newton and Aries [22].

Description of the Process Design Basis

The raw material for the process is ground cellulosic wastes while the end products are glucose and a mixture of single cell protein and an unhydrolyzed cellulose. The glucose can be used as an edible carbohydrate source and the protein-cellulose mixture is envisioned as an animal feed or feed supplement. The latter possibility has not been demonstrated as yet.

The plant size chosen for this study is based on a daily waste cellulose feed of 10 tons. The amount of products are estimated to be 5 tons of glucose and 5000 pounds of an animal feed supplement consisting of 50 percent single cell protein and 50 percent partially degraded cellulose. It is envisioned that a plant of this type would be located within a short distance of the source of the waste material. Costs for transportation, separation, and grinding of the cellulosic waste material are not included.

In the design, the following further assumptions are made:

1. The land necessary for the plant is already owned and available.
2. There is a market for the single cell protein-cellulose mixture as a feed supplement.
3. As a municipally owned and operated plant it is tax-exempt.

4. The disposal of the waste cellulose should be considered as a credit, although this is not taken into account in the cost estimation.

General Process Description

The process consists of the following steps:

1. Feed preparation: The ground cellulose waste is placed in a water suspension along with the necessary inorganic mineral nutrients.

2. Cellulose fermentation: In this, one of the two main steps in the process, S. myxococcoides is grown in a continuous culture on a cellulose substrate. It is during this step that the protein and cellulose enzyme solutions are produced. On the basis of preliminary data, it was assumed that decomposition would be complete in five days.

3. Separation of enzyme solution: In this step the cellulose enzyme solution is separated from the cell material and cellulose by means of centrifugation.

4. Cellulose hydrolysis: This is the second main step of the process. The cellulose enzyme solution produced in the fermentation step comes in contact with a second feed stream of cellulose and a hydrolysis to glucose occurs. Bacterial growth is prevented by the presence of toluene, an antiseptic. Available data formed the basis for assuming that hydrolysis would be complete in 25 days

5. Separation of glucose solution: Here the dissolved glucose is separated from the nonhydrolyzed cellulose. This is accomplished by centrifugation.

6. Recovery of single-cell protein: In this step, a bleed is taken from the stream recycling the cell material-cellulose mixture back to the fermenter. This suspension is dried and then packaged for use as an animal feed supplement.

7. Glucose purification and recovery: Finally, the glucose solution leaving the centrifuge is concentrated in an evaporator and crystallized. The glucose crystals are then washed and dried.

An estimated materials balance of the process is presented in Table 19. Process water and substances present in small amounts are not considered.

Cost Factors

The major equipment, size of the components and their costs, are given in Table 20. Items involved in arriving at an estimate of fixed capital are given in Table 21. Manufacturing costs are itemized in Table 22.

Net Waste Treatment Cost

Assuming a sales price of $0.14 per pound for the glucose product and $0.05 per pound for the feed supplement, the net sales per day would be $1650. The daily net operating cost, therefore, would be $2065 − $1650, or $415 per day. The cost per pound of treated cellulose waste, therefore, would be $0.021 or $42 per ton.

TABLE 19

ESTIMATED MATERIALS BALANCE FOR PROPOSED CELLULOSE CONVERSION SYSTEM

(Based on 20,000 lb/day)

Material	Waste Cellulose	
	Input lb/day	Output lb/day
Cellulose	20,000	
Nitrogen (as $NaNO_3$)	300	
Oxygen (as air)	6,700	
Water (for hydrolysis)	1,100	
Feed Supplement		5,000
Glucose		11,100
Carbon Dioxide		8,000
Water (from cell respiration)		4,000
Total	28,100	28,100

TABLE 20

MAJOR EQUIPMENT FOR CELLULOSE CONVERSION SYSTEM[a]

Equipment	Size/Capacity	Material	Cost
Medium Preparation Vessel	12,000 gal	CS	$ 14,500
Medium Sterilizer	12,000 gal/day	CS	14,800
Fermenter	60,000 gal	SS	115,000
Centrifuges (2)	20 in. diam	SS	43,000
Hydrolysis Vessel	300,000 gal	SS	119,000
Evaporator	8,400 gal/day	CS	22,500
Crystallizers (4)	3,600 gal	CS	30,000
Agitated Tank Washer	3,600 gal	SS	14,800
Drum Dryers (2)	50 sq ft area	CS	28,400
Centrifugal Pumps (6)	20 gal/min	SS	3,000
Total			$405,000

[a] Paper to be treated, 10 tons/day

TABLE 21

FIXED CAPITAL ESTIMATE FOR CELLULOSE CONVERSION SYSTEM

Purchased Equipment	$ 405,000
Installation	107,500
Piping	155,000
Instrumentation	64,500
Insulation	34,000
Electrical Auxiliaries	43,000
Building	215,000
Land and Improvements	43,000
Utilities	107,500
Physical Plant Cost	1,174,500
Engineering and Construction	300,000
Direct Plant Cost	1,474,500
Contractors Fee	75,000
Contingency	150,000
Fixed Capital	$ 1,699,500

TABLE 22

MANUFACTURING COSTS FOR CELLULOSE CONVERSION SYSTEM

	Per Day
Raw Materials	$ 60
Labor	472
Supervision	50
Maintenance	220
Plant Supplies	33
Utilities	340
Direct Manufacturing Cost	1175
Payroll Overhead	60
Laboratory	40
Plant Overhead	200
Packaging	100
Indirect Manufacturing Cost	400
Depreciation	460
Insurance	30
Fixed Manufacturing Cost	490
Manufacturing Cost	$ 2065/day

Discussion of Process Economics

It should be emphasized that the cost estimate made in this analysis is based on rather extensive assumptions, some of which may be conservative. On the other hand, it does not include costs of separation and grinding, operations which may add materially to the net cost. However, if biofractionation is only a part of an overall recovery program, then the two costs may be prorated among the various recycling processes. At any rate, the results of the analyses should be viewed only as being on a rough order of magnitude. A major cost factor is the large size of the fermentation and hydrolysis vessels necessitated by the slow growth of the organism and the slow rate of hydrolysis of the cellulose as reported in the literature. There is reason to believe that organisms and process conditions leading to a considerable reduction in vessel size may be found in future study. For example, Ghose [24] very recently reported cellulose hydrolysis with Trichoderma viride culture filtrates at rates approximately four times those assumed in the present design. Other process improvements may also be possible. A very modest reduction in the manufacturing costs dependent upon these rates could make the process self-supporting. Moreover, it is likely that the market value of glucose and protein will increase considerably in the future.

ECONOMICS OF WET OXIDATION

Introduction

The wet oxidation system as applied to solid wastes processing has been described in the First Annual Report [1] and is treated again in Chapter IX of this report. The process under consideration in this analysis would be applied to solid wastes in general with a disposal-organic chemical recovery objective in mind. Equipment requirements and cost estimates are based on published data [25-27] for the West-Southwest Wet Oxidation Plant of the Metropolitan Sanitary District of Chicago, Illinois, corrected for scale and inflation. Organic chemical production potentials are based on the results obtained by D. L. Brink [28] with the reaction of molecular oxygen and wood in an unbuffered aqueous system.

Process Evaluation

For the purposes of this analysis, wastes material entering the wet oxidation process will be considered equivalent to the solid wastes production (domestic and some commercial) of a city of 40,000 people or 100 tons per day of material. Such wastes would undergo preliminary separation and size reduction before entering the reactive phase of the process. Recoverable metals of commercial utility would be directed to salvage operations, while other metals and high-density materials would be diverted to landfill operations. The remaining material, primarily organic wastes, would be mixed with water-borne wastes, such as municipal and industrial sewage, or aqueous effluent from the process, or both, and wet ground to 1/4-in. or less particulate. These operations — separation, diversion, and size reduction — would be done at the process site. The subsequent treatment given the wastes is summarized in the flow diagram in Figure 2.

The aqueously dispersed wastes, containing about 10 percent solids by weight, will be pressurized, mixed with air, heated, and introduced into a two-stage reactor. Reactor conditions will be 220° to 260°C and 500 to 1000 psi. Effluent from the first stage, a partial oxidation stage, would be separated centrifugally and the aqueous phase directed to organic chemical recovery operations. The residual solids will be mixed with the stripped aqueous effluent from the chemical recovery operations or aqueous effluent from the second stage and introduced into the second stage for complete oxidation. Effluent from the second stage would be passed through heat exchangers and separated from noncondensable gases. These gases will be scrubbed and expanded to recover power for air compression. The residual solids will be separated by vacuum filtration and directed to landfill operations. The aqueous filtrate will be returned to various stages of the process as indicated above.

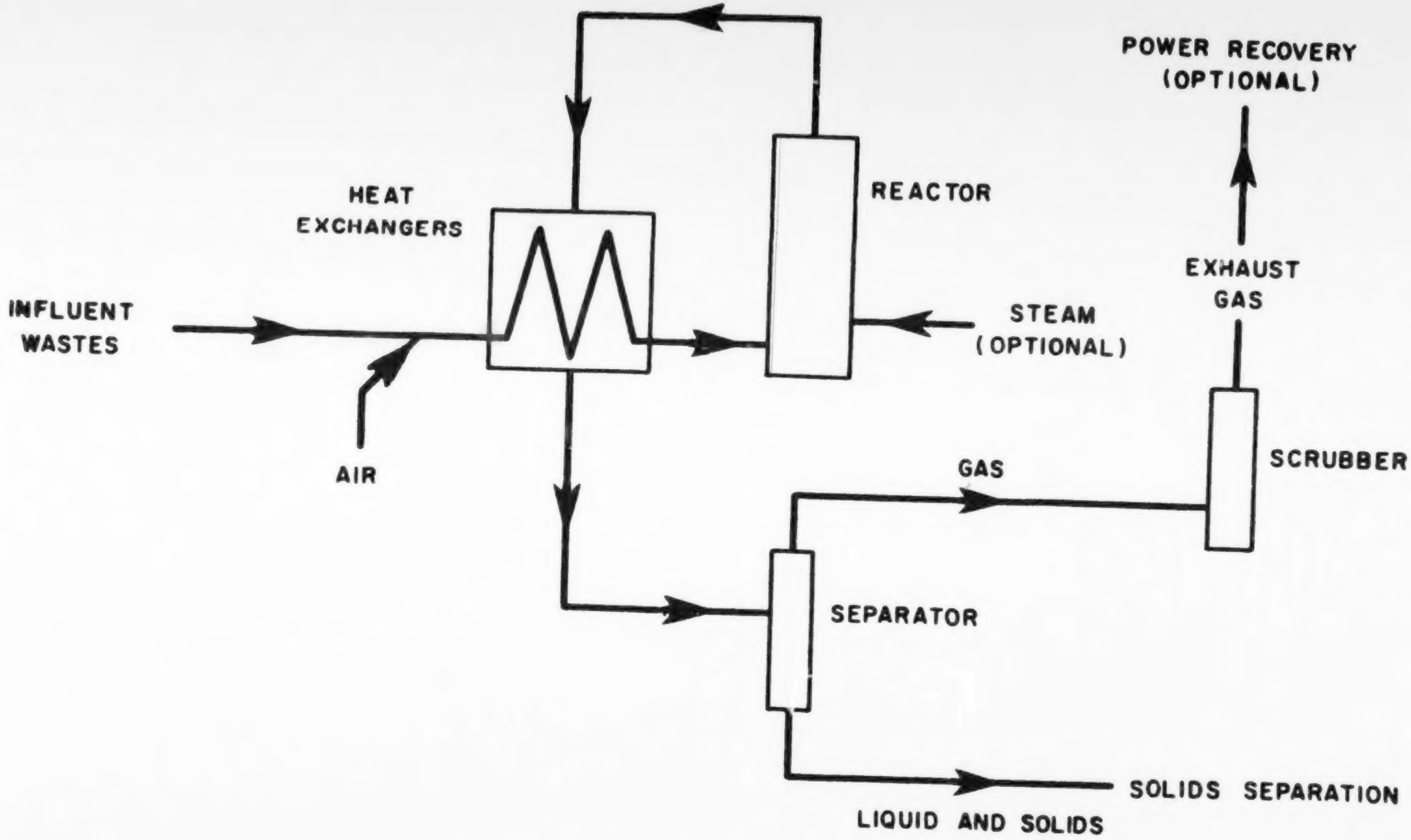

POWER RECOVERY
(OPTIONAL)
HEAT
EXCHANGERS
REACTOR
EXHAUST
GAS
INFLUENT
WASTES
STEAM
(OPTIONAL)
AIR
GAS
SCRUBBER
SEPARATOR
SOLIDS SEPARATION
LIQUID AND SOLIDS

FIGURE 2. FLOW DIAGRAM OF A GENERALIZED CONTINUOUS WET OXIDATION SYSTEM

The process as described would eliminate 90 percent or more of the organic material in the wastes influent involved with sufficient thermal and mechanical energy production to make the process self-sustaining. In addition, about 50 percent of the oxidized organic material would be recovered as discrete chemicals of commercial utility. On a weight basis, for every 100 tons of solid wastes processed, about 10 tons would be returned for landfill, 45 tons converted to organic chemicals, and 45 tons oxidized to carbon dioxide and water.

Equipment Requirements

Specific equipment requirements for the preliminary separation and size reduction of incoming wastes materials will not be listed because of the dependence of these requirements on the composition of the solid wastes involved. Similarly, no requirements will be given for organic chemical recovery because recovery may involve one or several operations such as distillation, extraction, precipitation, crystallization, or vapor phase deposition.

The wet oxidation process, per se, will be built around a stainless steel lined reactor, 4 ft in diameter and 40 ft high, designed to operate at 1000 psi and 260°C. There will be 6 heat exchangers with a 3000-sq ft heating surface. The aqueously dispersed wastes will be pumped to the reactor by a high pressure pump with a rated capacity of 180 gpm at a discharge pressure of 1000 psi. This pump in turn would be fed by a centrifugal sanitary pump. Compressed air will be furnished to the process by a 4500-hp, multistage compressor with a rated free air displacement of 9600 cfm at 1000 psi. Exhaust gases from the process will be expanded through a turbogenerator to produce 6250 kw-hr of power. Reactor effluent will be filtered on a 160-sq ft rotary belt vacuum filter.

The pumps, compressor, vacuum filter, and automated process controls will be housed in a 4000-sq ft building; the reactor, heat exchangers, and intermediate storage facilities will not. The whole process will cover about 7000 sq ft and may be located on any urban or rural site with little or no pollution restraint.

Costs

The proposed wet oxidation process, exclusive of preliminary separation and size reduction and chemical recovery facilities, will cost about $3,820,000* to build. Of this amount, $2,860,000 would be for the purchase and erection of the major equipment items of the process. The remainder would be allocated to the foundation, steel framework, maintenance facility, electric utilities, and other items. Calculated on a 25-year amortization period, this amounts to a $4.20 per ton capital cost. Operating costs for this process – labor, lubricants, chemicals, replacement parts, and power – would amount to $4.58 per ton. Combined capital and operating costs would total $8.78 per ton.

Costs related to preliminary separation and size reduction, chemical recovery, and disposal of wastes material diverted from the process or residual solids discharged from the process would have to be added to the above wet oxidation cost.

Part of the above costs, however, would be defrayed by salvaged metals and recovered organic chemicals. Assuming a chemical value of 6 to 10 cents per pound, the annual organic chemical production of the wet oxidation process, some 32.8 million pounds, would have a gross value of 1.97 to 3.28 million dollars, or a revenue value of 54 to 90 dollars per ton of solid wastes processed.

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*Wet oxidation costs calculated on a volume and weight of wastes material handled basis as one-fifth of that for the West-Southwest Wet Oxidation Plant and corrected for a 3 percent per annum inflationary rise.

Conclusion

The process of wet oxidation cannot be ruled out at this time on the basis of economics as a possible method of organic wastes management, even though extensive study is yet to be made of the problems involved in scaling up from pilot plant to prototype, segregating materials for processing, and in determining the full spectrum of organic wastes which can be processed.

ECONOMICS OF PYROLYSIS

Introduction

Operating costs of incineration of solid wastes according to various literature sources vary from $4.25 to $6.00 per ton-day, assuming continuous operation. Capital costs vary from $10,000 to $15,000 per ton for a plant of 200 ton per day capacity, exclusive of land and advanced air pollution control equipment. The installation of the air pollution equipment to meet the demands of modern regulations would materially increase the plant costs.

In estimating capital and operating costs for a pyrolysis-combustion plant employing the principles outlined in this report and as represented in Table 23, additional factors must be considered. These include utilization of pyrolysis gases in production of heat in a boiler operation and possible predrying of certain types of solid organic wastes after comminution.

Proposed Design

The basic design presented in Table 23 is envisaged as being embodied in a solid wastes pyrolysis-combustion unit. To pyrolyze 200 tons per day, two first-stage pyrolysis units would be required to feed into a single second-stage unit. Solid wastes would be fed to the two first-stage units through an appropriate feeding mechanism. This mechanism would in turn be preceded by appropriate classification, separation, and predrying, if needed, of the solid wastes. Hence costs have been estimated under the conditions noted and are as presented in Table 23.

Discussion and Conclusions

Based upon these preliminary estimates, the capital costs of a 200-ton per day pyrolysis-combustion process with generation of by-product steam and based on continuous operation will be on the order of $9025 per ton-day of solid wastes. Operating costs, based upon 24-hour continuous operation including grinding of feed material are on the order of $5.05 per ton. The calculation of steam is based upon a solids feed of 50 percent moisture. (The moisture content of municipal refuse generally averages about 35 percent.) On this basis, the value calculated for steam produced is $5.00 per ton of refuse pyrolyzed. Apparently, therefore, the disposal of organic solid wastes by this process, assuming a market for the steam or the possibility of generating electricity, would defray operating costs. Therefore, depreciation of capital costs would be the only cost involved. With an improvement in earnings from steam generation, the process can conceivably be designed so that it would be self-supporting.

In considering these estimates and the apparently favorable economics of the system, it should be kept in mind that the figures are very preliminary in nature and that the system has not been tested with solid wastes as yet. On the other hand, the system has been successfully tried with kraft black liquor as the feed. The principal difference with respect to using solid wastes as a raw material, will be the need to develop a suitable mechanism for charging or feeding the solid wastes into the system.

TABLE 23

PRELIMINARY ECONOMIC ESTIMATE FOR PYROLYSIS-COMBUSTION SYSTEM OF DISPOSAL OF SOLID WASTES FOR A 200-TON/DAY SOLID WASTES CAPACITY (OVEN DRY BASIS)

	Installed Cost ($)
A. PLANT COSTS:	
Two Carbon-Steel Reactors (3 ft diam x 30 ft high)	10,000
Two Furnaces for Above (complete with instrumentation)	400,000
One Stationary Cylindrical Furnace (6 ft diam x 30 ft high; complete with instrumentation)	400,000
One Multicyclone System	20,000
One Waste-Heat Boiler (56,000 lb/hr capacity)	225,000
One Scrubber	14,000
Two Feed Systems for Stage 1 Reactors, plus Cyclone Separator, etc.	200,000
1. Total Equipment Costs	1,269,000
Piping (20 percent of total purchasing cost excluding furnaces $469,000)	103,000
Instrumentation (15 percent of total purchasing cost excluding furnaces)	70,000
Control Room	25,000
2. Cost of Physical Plant	1,467,000
Engineering (7 percent of physical plant cost)	103,000
3. Direct Plant Cost	1,570,000
Contingency (15 percent of direct plant cost)	235,000
4. Total Plant Cost	1,805,000
B. ANNUAL DIRECT OPERATING COSTS[a]:	
Eight Operators ($10,000 each including fringe benefits)	80,000
Supervision	15,000
Maintenance (5 percent of physical plant cost)	73,400
Water and Electricity	15,000
Insurance and Miscellaneous	30,000
5. Total Annual Operating Costs	213,400
6. Direct Operating Cost/ton-day	3.05
Grinding Costs/ton-day (200 tons at $2.00/ton)	2.00
Total Operating Cost/ton-day	5.05
Earnings from Generation of Steam/day[b,c]	1,010
Earnings from Generation of Steam/ton-day	5.00

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[a] Continuous 24-hr/day, 7 days/week, 350 days/year operation

[b] By-product steam value at $0.75/1000 lb

[c] Heat value of solid wastes feed assumed to be 5000 BTU/lb

VI. PUBLIC HEALTH

INTRODUCTION

From a consideration of the nature of the problem of solid wastes management summarized in Chapter II it seems evident that there are significant differences between the planning, operations research, economic, and technological aspects of the problem on the one hand, and the public health aspects on the other. In fact, it might be said that while lack of attention by land-use planners has created the Number One problem of wastes management, long-time attention by public health agencies has so contained the health problem that the unwary observer sometimes questions whether such a problem exists at all. This makes it necessary that careful consideration be given to the nature and relative magnitude of research effort appropriate to the public health aspect of the research program.

A need for such evaluation became evident early in the study and was discussed in some detail in the First Annual Report [1]. Although the research herein reported represents a continuation of the work in progress at that time (1967), some further analysis of the role of public health, both in solid wastes management and in research in that field, seems basic to a full understanding of the progress reported.

RELATION OF SOLID WASTES MANAGEMENT TO DISEASE

Solid wastes management has traditionally been regarded as a problem in public health, generally because of the belief that unless properly handled, wastes can constitute a hazard in terms of the etiology of disease. Possibly, the reason for this automatic association of solid wastes with spread of disease dates back to the preplumbing days when night soil was an important fraction of the total mass of solid wastes which at various times in history and in various cultures has been permitted to accumulate in the streets.

Despite this long-term association of health hazard with solid wastes, it would be hard to pin down specific instances in which an outbreak of disease can be unequivocally related to solid wastes management practices. For example, in a study conducted by the Aerojet-General Corporation for the U. S. Public Health Service [29], 1236 publications were read and abstracted without finding sufficient data to permit a quantitative estimate of any solid wastes-disease relationship, although circumstantial and epidemiologic information was found which gave reason for concluding that such wastes do have a definite, if not a well defined, etiologic relationship.

The failure to demonstrate a direct relationship between poor management of wastes and spread of disease does not necessarily imply a lack of connection between public health and solid wastes management. It may be that the diseases thought of in this context never really existed as environmental problems peculiar to solid wastes, even though their solution may not have been possible unless the solid wastes aspect was resolved. For example, a poorly managed disposal site can serve as a shelter, food supply, breeding place, or focal point for vectors which can transmit disease, but good solid wastes management alone is by no means the only action necessary to control such vectors. However, if the vectors are effectively controlled, the problems involved in that control with respect to solid wastes management cannot be correlated with the diseases which the vectors are capable of transmitting, for the simple reason in logic that eliminating a cause precludes a result. Thus one type of public health problem having relevance to wastes management may be said to exist more as a threat than as a visible problem requiring definitive experimental research. It is this sort of problem which in Chapter II is called Type 1 and described as being reasonably well solved, although remaining solved only at the price of constant vigilance.

Solution of problems before they become identified to a significant degree with solid wastes may not be the only reason for the uncertain linkage between wastes and disease. It may be that the term "health" has been interpreted in too narrow a sense, i.e., as freedom from disease and infirmity. It may also be that a lack of information exists because no study has been made in which the entire gamut of wastes is considered. Or it may be that primary concern has been for the biologic agents of disease to the neglect of chemicals which either directly or through decomposition products pose hazards to health. Through the years, chances have grown more remote for pathogenic biological agents to enter the environment by way of solid wastes. The same may not be said of chemicals. There is a growing literature on the subject of leaching from landfills, as well as on the pollution of air resulting from incineration and on the toxic nature of various chemicals and metals which are used in industry and hence may be presumed to find their way into solid wastes.

It might be concluded therefore that failure to find any convincing evidence of the relation of solid wastes management to disease may mean that available information relates only to the first of the three types of problems identified in Chapter II. Nevertheless the subject merits more consideration in relation to the role of public health in environmental control of solid wastes, along with a similar examination with respect to the other two types of problems cited in Chapter II, i.e.,

Type 2 Those which are as yet unresolved; and may not be solved apart from other solid wastes management problems.

Type 3 Those which remain unevaluated in comparison with other more obvious environmental hazards, or are still unidentified as problems in public health.

ROLE OF PUBLIC HEALTH IN SOLID WASTES MANAGEMENT

Two distinct roles of public health specialists in solid wastes management are identified in the First Annual Report of the project herein reported. One of these is regulatory; the other investigative. The regulatory role involves participation in the establishment of appropriate legal ordinances and in a program of surveillance of the entire solid wastes management activity in all of its phases from on-site storage to disposal by whatever method. It is by this activity that health problems of the first type cited in Chapter II are kept under control. On a research team the presence of public health specialists having an awareness of the requirements and underlying rationale of this regulatory activity serves to keep other researchers alert to certain practical realities and constraints imposed by health considerations.

In his role as a researcher, the public health, or environmental health, specialist functions in a variety of ways. Data on which regulatory criteria are established and refined, particularly those related to vector control, have normally come from research activities in which vectors rather than solid wastes *per se* motivated the investigation. Thus it might be said that interest in the public health aspect of solid wastes predated widespread attention to solid wastes management problems in general and played an important role in identifying such problems and in defining some of the necessary objectives of a program of research directed to their solution.

As noted in Chapter II, the second type of public health problem is concerned with occupational hazards and with psychological and sociological responses of people to environmental conditions. In this type of problem the public health researcher often finds his interest broader than the solid wastes aspect of environmental management. Consequently he is likely to bring to the solid wastes research team on which he serves, information from other investigative work in sociological and related problems apart from the solid wastes study itself.

In relation to the third type of problem, the public health researcher tends to play the dual role of investigator and interpreter. Again as noted in Chapter II, the fact of toxicity or health hazard of any specific material, as well as information on the concentration at which it is significant, is a matter for medical and epidemiological research which may proceed quite independent of solid wastes management considerations. Thus the public health specialist concerned with solid wastes problems is likely to be called upon to assess the health significance of various components of solid wastes during the management routine, on the basis of knowledge gained by himself and others in a separate research context which may have broader implications. This does not mean that the quest for knowledge of the health significance of individual fractions of solid wastes is not an appropriate aspect of research on solid wastes management. It does, however, pose the problem of which of the vast spectrum of components of solid wastes, if any, should be investigated in a solid wastes management program of limited budgetary support; and calls for value judgments of which components of refuse are likely to prove significant and which trivial in health consequence.

NATURE AND RESULTS OF INVESTIGATION

The principal objective of the research herein reported was systematically to screen data on the types and composition of solid wastes and on the processes of disposal for the purpose of:

1. Identifying those fractions which might have public health implications.
2. Evaluating the public health significance and environmental fate of the various fractions in relation to wastes processing or disposal.
3. Identifying those constituents of the solid waste stream which merit intensive study, as well as the point in the management procedure where such study should begin.
4. Suggesting means of keeping those components shown to constitute a significant hazard from entering the environment in such a manner as to come in contact with man.

A second responsibility undertaken by the public health specialists on the project was to evaluate, on a continuous basis, the proposals and findings of other aspects of the project for public health implications which might be overlooked, or which might generate new health-related problems. This responsibility was generally advisory and consultative in nature and concerned problems of the sort cited as Type 1 and Type 2. No findings of particular import resulted from this aspect of the project. Consequently the results herein reported derive from the screening study.

Procedure

A series of tables was prepared by a survey technique involving five major steps as well as the exercise of value judgments of both qualitative and quantitative factors. These steps were sequential in nature and included:

1. Classifying of wastes as to source (e.g., domestic, industrial, etc.).
2. Identifying of the individual components of each class (e.g., wood, iron, plastics, etc.).
3. Listing of the chemical nature of each component (e.g., cellulose, lignin, etc.).

4. Listing the chemical nature of any breakdown products to which each component might be converted in each of the several disposal processes (i.e., incineration, landfill, composting).

5. Assessing the public health significance of the components and their breakdown products.

In making the evaluation necessary to Step 5, three criteria were utilized as a basis for value judgments:

1. Magnitude of the component in the waste stream.

2. Likelihood of a given component entering man's environment.

3. The effect on the public health of any given component if released to the environment.

In applying these criteria it was, of course, recognized that magnitude is a relative term in the context of health significance. Trace amounts of one class of substance might have a profound effect on public health were it released to the environment, whereas large amounts of other types might be present before they constitute a threat to the public health. An example of the former is cadmium. Ingestion of a milligram or two per kilogram of body weight is sufficient to have dire effects on an individual. On the other hand, an appreciable amount of iron is needed to constitute a hazard. In either case, however, the significance of any substance in any amount in solid wastes is dependent upon it being released to the environment under circumstances which might injure man, either directly or through depletion of his crops or animal resources. Inasmuch as both original substances and their breakdown products may be involved and the long-term significance of dangerous materials sequestered in the ground are speculative, a considerable degree of subjective reasoning enters into an evaluation of the likelihood that any material will enter the environment even if it is present in the waste stream in significant amounts. Obviously, an insoluble material has a far less chance of entering the environment than one that is highly soluble.

In assessing the effect on public health if a toxicant is released to the environment at any stage in solid wastes management, a choice has to be made between individual health and epidemiological significance. For the purpose of this report the criterion is adopted that if a material is harmless to the average individual's health (without attempting to define an "average" individual) it is of little public health significance. Conversely, if it is a hazard to an individual it is considered a public health hazard if released to man's environment.

Investigative Findings

The results of the investigative work herein reported are summarized in Tables 24 through 28 inclusive. The sources used in arriving at the information presented in the tables are found in the References at the end of the report. In preparing these tables consideration was first given to the myriad ways in which solid wastes might be classified. For example, one might choose to adopt the traditional approach which identifies wastes in relation to environmental origin, e.g., domestic, commercial, industrial, etc. On the other hand, wastes might be classified according to their nature, e.g., metals, plastics, wood, etc. In the first instance the material itself (e.g., wood) must be reconsidered in relation to each origin. In the second, the origin must be repeated in regard to each material considered.

When evaluating the public health significance of individual materials in wastes disposal processes the second approach would seem the most logical, provided all community or regional wastes were combined in a single mass for disposal. Although the rationale underlying the study herein reported is that a regional approach to solid wastes management is necessary, the fact remains that public responsibility for wastes disposal is still oriented to domestic refuse while other wastes producers make various arrangements to dispose of their own wastes. The result is that so little is known concerning the nature and amount of wastes from individual origins that research needs in some instances are first to identify and quantitate wastes materials before any public health evaluation based on degree of hazard can be made. For this reason environmental origin was adopted as the basis of classification for Tables 24 through 28.

The tables themselves must be considered in the nature of "work sheets" to which data or value judgments may yet be added, but from which conclusions are herein drawn relative to the health significance of various components of wastes and to identifiable research needs. See references [30-69] for the materials used in compiling the tables.

The overall nature of the tables may be explained by reference to Table 24. In setting it up the authors first list the principal constituents of domestic wastes that contribute a fraction of the class of material to be considered. For example, the general class of Metals includes such things as "cans," which are essentially 100 percent metal, and "luggage," of which plastics, wood, or leather may be the major component. However, in relation to metals only the type and fate of that fraction of the item is considered at this point in the table. Therefore "luggage" appears again in Column 1 of the table when other of its constituents is the subject of consideration.

In Column 2 of the table the "type" of material (e.g., kind of metal) is listed. In Columns 3 and 4 the kind of conversion products which may appear in the air, water, or land resource during or as a result of disposal processes are tabulated. It is particularly important to note that the spectrum of products includes those that are possible under some level of operation of the method cited. For example, the products of incineration may include those which can come from open burning as well as those from proposed high temperature furnaces. There is no attempt to argue the point that the best operation or the most effective system presently technologically possible will prevent some of these products from entering the environment. Instead it is recognized that in the real world these products do exist and sometimes follow the pathways suggested; and that as long as such is possible, any attendant public health hazard must be presumed to exist.

In the column headed "Identified Public Health Significance" (Column 5) the entries represent only the principal factors recognized by the project personnel at the time the table was prepared. It does not, unfortunately, represent the aggregate knowledge of mankind concerning the health implications of the materials cited.

In the final column of the table (Column 6), technological and medical, as well as environmental health, research needs are indicated. Furthermore, as discussed in a subsequent section, consideration was given to the possibility that the research need might concern the knowledge gaps at any point in the table, i.e., in any of the Columns from 1 to 5.

In Table 24 percentages of various classes of materials (e.g., metals, 7 percent of total domestic refuse) are included where such data are available. These values represent information from some actual analyses but are not necessarily the national average nor applicable to any individual community. They do, however, total to 100 percent and give some basis for judging the public health importance of the conversion products of any particular major constituent of domestic refuse. No data are available on the percentage of each type of industrial wastes listed in Table 25. Such would be essentially meaningless in any individual case because regional or local patterns of industrial diversity are highly variable. This lack of data does, however, underscore the importance of studies leading to an estimate of our national industrial wastes load and its environmental significance. In Tables 26, 27, and 28, available values are presented which give scale to the magnitude of any associated health problems.

TABLE 24

PUBLIC HEALTH EVALUATION OF DOMESTIC WASTES

Source 1	Type 2	Environmental Fate of Material and Conversion Products in Relation to Disposal Method		Identified Public Health Significance [at present (1968) stage of project] 5	Suggested Research Needs 6
		Incineration 3	Sanitary Landfill and Composting 4		
		METALS (Approximately 7% of Total)			
Cans Aluminum foil Kitchenware Cutlery Appliances Furniture House fixtures Razor blades Tools, nails, etc. Toys Clothing hangers Blinds and shades Pails Bottle caps Ash trays Plumbing fixtures Luggage Batteries Shoes Doormats Crates Paint Paper Glass Pens Lamps (incandescent and fluorescent) Radio sets Television sets Miscellaneous other electronics Cloth Leather goods Mineral "ash" Miscellaneous junk	Iron (Fe) Aluminum (Al) Tin (Sn) Zinc (Zn) Lead (Pb) Copper (Cu) Silicon (Si) Carbon (C) Nickel (Ni) Magnesium (Mg) Cadmium (Cd) Selenium (Se) Varadium (V) Tungsten (W) Beryllium (Be) Mercury (Hg) Titanium (Ti) Sulfur (S) Silver (Ag) Gold (Au) Chromium (Cr) Calcium (Ca) Sodium (Na)	1. Appear in metallic form in residue to reclamation or landfill: Fe, Al, Pb, Zn, Cu. 2. Appear as relatively inert compounds in ash to landfill: FeO; Fe_2O_3; Al_2O_3; SiO_3; CrO_2; CrO_3; Cu_2O; CuO; ZnO; SnO; V_2O_2; V_2O_3; V_2O_4; NiO; Ni_2O_3; Ni_3O_4; CdO; Cd_2O; PbO; PbO_2; Pb_3O_4; Pb_2O_3; Pb_2O; SeO; HgO; TiO_2; Ti_2O_3; MgO; CaO. 3. May appear as particulate matter in stack discharges. (See 2, above.) 4. May appear as vaporized metal in stack discharges: Al; Be; Zn; Hg; Se; Pb; Cd. 5. Appear as gases in stack discharge: CO_2; CO; SO_2; SO_3. 6. Appear in stack discharge as by-products of incineration process: N-oxides.	1. Remain in landfill as inert or relatively inert compounds unless fill eroded by surface runoff: Uncombined metals; Al_2O_3; $Al(OH_3)$; FeO; FeO_2; $Fe(OH)_2$; $Fe(OH)_3$; CrO_2; Cr_2O_3; $Cr(OH)_2$; Cu_2O; CuO; $Cu(OH)_2$; SnO; ZnO; $Zn(OH)_2$; V_2O_2; Be; BeO; NiO; Ni_2O_3; $Ni(OH)_2$; CdO; Cd_2O; $Cd(OH)_2$; PbO; Pb_2O_3; Pb_3O_4; Pb_2O; Se; SeO_2; Hg; HgO; TiO_2; MgO; $Mg(OH)_2$; $Ca(OH)_2$; $CaCO_3$. 2. May leach to groundwater: Ca and Mg sulfates; Fe, Ca, and Mg bicarbonates; CO_2; also oxides of Sn, Zn, Cu in acid water. 3. Escape to atmosphere: essentially none.	1. Particulate lead in air may cause chronic intoxication; soluble lead compounds are cumulative poisons. Percentage of lead in air due to disposal of domestic wastes not significant. 2. Particulate beryllium produces pulmonary fibrosis. Hazard to workers in solid wastes disposal possible; hazard to public from this source unknown. 3. Inhalation of cadmium oxide dust or fumes may cause pulmonary endema or hemorrhage and can be fatal. Hazard to public from solid wastes disposal unknown. 4. Inhalation of zinc fumes or finely divided zinc oxide may result in "metal fume fever," and damage to epithelial cells in the respiratory tract. Hazard from domestic fraction in relation to industrial fraction of wastes unknown, as is overall hazard of zinc in solid wastes. 5. Particulate matter reduces clarity of atmosphere. Heavy metals (e.g., Cr and Ni) may produce cancer. 6. CO and oxides of nitrogen and sulfur known air pollutants. Relative contribution of incineration of domestic metal wastes probably insignificant. 7. Compounds of Cr, Cu, V, known to be toxic. Oxides of Fe, Cu, Zn, Sn toxic. Contribution from domestic wastes probably not important. 8. Mercury vapor deadly. Trivial constituent of domestic metal wastes.	1. Investigation of exposure of refuse "tippers" and equipment operators to beryllium might be useful. 2. Analysis of incinerator stack discharges for types and amounts of various metallic compounds needed, including degree of removal by various fly ash and particulate control devices. 3. Medical research is needed on toxicity levels of compounds of metals such as cadmium and selenium which are coming into wider use in the U. S. 4. Studies needed to establish existing background level of dangerous metal compounds in urban concentrations - possibly on methods of making such analyses. 5. Extend current studies on toxicity of metals and metal oxides to animals (men) and plants.

TABLE 24 (Continued)

1	2	3	4	5	6
CLOTH - Natural and Synthetic Fibers (Approximately 4% of Total)					
Rags Furniture upholstery Rugs, carpets Apparel Curtains, drapery Bags String, twine, rope Luggage Shoes Toys Doormats Tires	Rayon Dacron Nylon Dekton Other synthetic fibers Cotton (cellulose, 83%) Wool (keratin - C 50%; H, 7%; O, 22%; N, 17%; S, 9%) Linen (cellulose, 82%) Silk (C, 48%; H, 6%; N, 20%; O, 26%) Hemp Sisal	1. Appear as gases in discharge: CO; CO_2; SO_2; S_2O_3; SO_3. 2. May appear in stack discharge as products of synthesis and incomplete combustion: aldehydes; ketones; low molecular weight hydrocarbons; HCl chlorinated hydrocarbons; polynuclear hydrocarbons. 3. Appear in stack discharge as by-products of incineration process: N-oxides. 4. May appear as particulate matter in stack discharge.	1. Remain in landfill as inert or relatively inert materials: a. Materials fabricated of synthetic fabrics. b. Oxidized and reduced minerals in "natural" fibers. 2. Remain in landfill by incorporation into microbial protoplasm: NH_4^+; reduced sulfur compounds: C; P; K. 3. May leach out to groundwater: CO_2; aldehydes; ketones; organic acids; sulfates; phosphates; NH_4^+; NO_2^-; NO_3^-. 4. Escape to atmosphere: CO_2; CH_4; volatile short-chain fatty acids; N_2; NH_3; H_2S; mercaptans (N_2 and CH_4 formation unlikely in composting).	1. Chlorinated hydrocarbons may damage central nervous system. Amount, and hence hazard to public unknown. 2. Aldehydes, HCl, ammonia, oxides of sulfur, H_2S, and nitrogen, CO and H_2S, are irritants and/or toxicants. 3. Some low molecular weight and polynuclear hydrocarbons are carcinogenic. Short-chain fatty acids, H_2S, and mercaptans are odorous. 5. Particulate matter reduces clarity of atmosphere. 6. CO_2 diffused in soil leads to pickup of hardness (no health significance). 7. Odors from landfill and composting may be nuisance in vicinity by site. 8. Items 2-5 significant only in vicinity of incinerator. Contribution to total air pollution is minor. 9. Quantitative data on item 6 unavailable, consequently hazard to public health unknown.	(See PLASTICS below)
PLASTICS (Approximately 1.9% of Total)					
Bags Wrappers Records Dishes and utensils Pens Appliance cases Brushes and combs Luggage Rain gear Apparel Shoes Floor covering Packaging	Polyethylene (38%) Polyvinylchloride (32%) Polystyrene (21%) Polyethylene acrylate copolymers Polyamide fluorocarbons Polysulfides Alleyl resinesters Polycellulose Polyalycols	1. May appear in stack discharge as products of synthesis and incomplete combustion: HCl; halides; aldehydes; low molecular weight hydrocarbons; low molecular weight polynuclear and aromatic hydrocarbons. 2. Appear as gases in stack discharge: CO; CO_2; SO_2; S_2O_3; SO_3. 3. May appear as vaporized plastic in stack discharge. 4. May appear as particulate matter in stack discharge. 5. Appear in stack discharges as by-products of incineration process: N-oxides.	Essentially inert in landfill	1. Chlorinated hydrocarbons may damage central nervous system. 2. Some low molecular weight hydrocarbons, particularly polynuclear and aromatic hydrocarbons are carcinogenic. 3. Aldehydes, halides, sulfates, HCl, respiratory irritants. 4. CO and oxides of sulfur and nitrogen are toxic and/or irritants in atmosphere. 5. Particulate matter reduces clarity of atmosphere. 6. Domestic refuse principal contributor of plastics to solid wastes; percent of total rapidly increasing, hence health implications of growing concern in incineration process. 7. Incineration products may cause odor nuisance. 8. Items 1-7 important in vicinity of incinerator Contribution to total air pollution is minor.	1. Process research needed to improve technology of incineration of plastics. 2. Scientific research needed to develop degradable plastics. 3. Environmental studies needed to evaluate the relative contribution of domestic wastes disposal and other sources of identified health-related air pollutants, particularly in local areas of significant concentrations.

TABLE 24 (Continued)

1	2	3	4	5	6
			LEATHER (< 1% of Total)		
Luggage Purses and Wallets Apparel Shoes, boots Upholstery Book binding Machinery belts	Protein Collagen Keratin	1. Stack discharge: See Items 1, 2, 4, PLASTICS (above). 2. Appear in stack discharges as by-products of incineration: N-oxides.	1. May leach out to groundwater: CO_2; aldehydes; ketones; organic acids; sulfates; phosphates; NH_4^+; NO_2^-; NO_3^-. 2. Remain in landfill by incorporation into microbial protoplasm: NH_4^+; reduced sulfur compounds; C; P; K. 3. May escape into atmosphere: CO_2; CH_4; volatile short-chain fatty acids; N_2; NH_3; H_2S; mercaptans (N_2 and CH_4 formation unlikely in composting).	1. Products of disposal methods similar to those of CLOTH. Little public health significance because of small amount in domestic wastes.	See CLOTH.
			RUBBER - Natural and Synthetic (Approximately 1.1% of Total)		
Tires Doormats Shoes Tile Rain gear Machinery belts Floor covering Apparel	Natural rubber (polyterpene - long chain of isoprene residues) Synthetic rubbers, e.g.: butadiene (acrylonitrile copolymer) neoprene ($CH = C\ Cl - CH = CH_4$) styrene isobutylene - isoprene chloroprene polysiloxane polymer	1. Stack discharge same as for PLASTICS (Items 1, 2, and 3); and for LEATHER (Item 2). 2. Appear in stack discharges as by-products of incineration process: N-oxides.	1. Synthetic rubber is essentially inert. 2. Natural rubber breaks down extremely slowly.	1. See Items 1 and 2, PLASTICS (above). 2. Dense black smoke characteristic of small incinerators burning rubber. 3. Odor nuisance accompanies burning of rubber. 4. Dust from tire wear on city streets adds to respiratory problems of urban dwellers. Quantity, hence importance unknown. 5. See Item 8, PLASTICS (above).	1. Medical and environmental research needed to assess the health hazard of particulates in street dust resulting from motor vehicle tires.
			GLASS (Approximately 8.0% of Total)		
Tableware Bottles, jars Lamps (incandescent and fluorescent) Mirrors Windowpane Miscellaneous containers Glass wool Glass fiber (woven) Decorative glass	"Soft" glass (e.g., Na_2O, CuO, SiO_2). "Hard" glass (e.g., B_2O_2 - 12%, SiO_2 - 81%).	1. Appears as inert material in ash to landfill.	1. Inert in landfill and composting process.	1. Broken glass may be hazard to men handling solid wastes. 2. May be aesthetically unacceptable in compost on soil. 3. In open fill uncrushed containers may retain food scraps and attract vectors, or hold water in which mosquitoes breed. 4. Items 1 and 2, are of local significance.	1. Technological research needed on ways to reprocess and reuse glass in order to reduce amount of wastes.

TABLE 24 (Continued)

1	2	3	4	5	6
WOOD (Approximately 2% of Total)					
Furniture Picture frames Boxes Crates Tree trimmings Luggage Sawdust and shavings Scrap lumber	Wood (Cellulose - 55%; Lignin - 24%; Pentosans - 18%; N - 0.2%; P - 0.1%; K - 0.2%; Terpenes-; Mono-; Sesqui-; Diter-; Triter-; Abietic Acids; Pimaric Acids; Esters)	1. Appear in stack discharge as combustion products: CO; CO_2. 2. Appear in stack discharge as by-products of incineration: N-oxides. 3. May appear in stack discharge as products of synthesis or of incomplete combustion: low molecular weight hydrocarbons; low molecular weight aromatic and aliphatic hydrocarbons; polynuclear hydrocarbons; phenols. 4. May appear as particulate matter in stack discharge. 5. Appear in ash for disposal to landfill: K_2O; KOH; phosphates.	1. May leach to groundwater: CO_2; aldehydes; ketones; organic acids; phenol; NH_4^+; NO_2^-; NO_3^-. 2. Remain in landfill through incorporation into microbial protoplasm: NH_4^+; C; P; K. 3. May escape into atmosphere: CO_2; CH_4; volatile short-chain fatty acids; N_2; NH_3.	1. See CLOTH. 2. Amount of N-oxides from wood burning is small. 3. Health significance of conversion products of wood in domestic wastes is small because of low-percentage of this component. 4. Wood and paper may be major source of fly ash in poor incineration; causing nuisance and loss of air clarity. 5. Nuisance insects (e.g., earwigs) may thrive in poor landfill. 6. Wood partially decomposed in composting process may serve as food for objectionable fungi and insects. May be significant in composting if use of product is widespread.	1. No particular need for research on Wood in domestic refuse. (See DEMOLITION DEBRIS for research needs on Wood.)
GARBAGE (Approximately 15.5% of Total)					
Cereal and grain products (0.5%) Meat trimmings and wastes (2.3%) Oils and fats (2.3%) Fruit (1.5%) Vegetables (2.3%) Egg shells, bones, coffee grounds (2.8%) Tree leaves (1.5%) Lawn trimmings (1.0%) Plants (1.3%)	Protein Sugars Starches Cellulose Fat Neutral fats Fatty acids Lignin Cellulose	1. Stack discharges same as for WOOD (Items 1, 2, 3, and 4), plus aldehydes, ketones, and acrolein.	1. Possible leachates to groundwater: See WOOD (above); plus sulfates, phosphates, and carbonates. 2. See Item 2, WOOD (above). 3. May escape into atmosphere: CO_2; CH_4; volatile short-chain fatty acids; H_2S; mercaptans; N_2; NH_3. (In composting, N_2 and CH_4 formation unlikely.)	1. Fly nuisance and danger of fly borne disease is a major public health concern with garbage. 2. Uncollected garbage in slums a major source of rat food; hence of rat bites and rat borne diseases 3. Insect and rodent vectors of disease harbored by poorly managed land disposal may constitute an important health hazard. 4. Odor nuisance of garbage an important environmental factor.	1. Environmental research on housing, slum clearance, social and cultural effect of poverty needed. 2. Technological research on refuse collection systems needed.

TABLE 24 (Continued)

1	2	3	4	5	6
PAPER (Approximately 51.5% of Total)					
Stationary (bond, envelopes, ledger, etc.) (2.8%) Books and magazines (6.8%) Newsprint (9.4%) Absorbent paper ("Tissue" products) (1.0%) Paper dishes (1.0%) Wrapping paper - brown (5.6%) Coated paper ("wax" paper, glazed paper, plastic-coated paper, cartons, containers) (1.5%) Cardboard (boxes, packing, etc.) (23.4%)	Kraft Ragstock Sulfite Sized Inked Wax - impregnated, glazed Plastic-coated Resins (urea formaldehyde; melamine formaldehyde; "natural" resins)	1. Appear in stack discharge as combustion products: CO; CO_2. 2. Appear in stack discharge as by-products of incineration: N-oxides. 3. May appear in stack discharge as products of incomplete combustion or synthesis: low molecular weight hydrocarbons; low molecular weight aromatic and polynuclear hydrocarbons; phenols. 4. May appear as particulate matter in stack discharge.	1. May leach to groundwater: CO_2; aldehydes; organic acids; phenol; NH_4^+; NO_2^-; NO_3^-. 2. Remain in landfill through incorporation into microbial protoplasm: NH_4^+; C; P; S. 3. May escape into atmosphere: CO_2; CH_4; volatile short-chain fatty acids; H_2S; mercaptans; N_2; NH_3. (N_2 and CH_4 formation unlikely in composting.)	1. Paper is principal source of harmful gases and particulates which may be produced by inefficient incineration (see CLOTH, Items 1 to 5) of domestic refuse. 2. Phenols produce taste in water. May come from degradation of sizing and coatings in landfill or composting process. 3. Amount of NH_3, H_2S, and mercaptans from paper is too small to have much public health significance. 4. Items 1 and 2 are of major significance in vicinity of incinerator. Contribution to total incineration is slight.	1. Principal research needs are technological: a. Control of combustion products; b. Recycling, reclamation, or conversion of paper. 2. (See Item 3, PLASTICS.)
UNCLASSIFIED FRACTION (5% of Total)					
Soil Ashes Bricks Tile Crockery Concrete Miscellaneous rubble	SiO_2 Fired clay Calcined $CaSO_4$ Cement	1. Appear as inert material in ash to landfill.	1. Relatively inert. 2. Ashes in fill may leach soluble minerals to groundwater reducing its chemical quality	(No health problems identified.)	(None suggested.)

TABLE 25

PUBLIC HEALTH EVALUATION OF INDUSTRIAL WASTES

Source 1	Type 2	Environmental Fate of Materials and Conversion Products in Relation to Disposal Method		Identified Public Health Significance [at present (1968) stage of project] 5	Suggested Research Needs 6
		Incineration 3	Sanitary Landfill and Composting 4		
		TEXTILE MILL WASTES			
Cotton Cotton gin wastes 1) Cotton seed burrs 2) Cotton fibers Cotton processing wastes 1) Starches used for sizing 2) Waterproofing materials Wool Wool grease Sand Suint Silk Silk worm cocoons Cloth and fiber residues General Textile Wastes Dye wastes Processing wastes Asbestos	Cellulose Lignin Cellulose and cellulose derivatives Aluminum acetate, aluminum formate, gelatin, wax Wool fiber (40%), [nitrogen (4-6%), phosphoric acid (3%), potash (2%), lanolin] Lignin Dried sheep perspiration Silk [nitrogen (10%), phosphoric acid (2%), potassium (1%)] Dichromate-acetic acid, tin and iron salts, dye pigments, bleach Benzoic acid, acetic acid, sulfonated oils, phenolic compounds, aliphatic and fatty esters, soaps Asbestos fiber	1. Appear in stack discharge as combustion products: CO; CO_2; S-oxides; P-oxides; N-oxides. 2. Appear in stack discharge as by-products of combustion: N-oxides. 3. May appear in stack discharge as products of synthesis or incomplete combustion: low molecular weight hydrocarbons; low molecular weight aromatic and polynuclear hydrocarbons; acrolein; phenol. 4. May appear as inert particulate matter: mineral ash; asbestos fiber; SiO_2. 5. Appear as mineral compounds or metals in ash to landfill: CrO_2; SnO; SnO_2; FeO; Fe_2O_3; K_2O; Al_2O_3; SiO_2.	1. May leach to groundwater: CO_2; aldehydes; organic acids; phenols; phosphates; chromium, iron, and tin salts; KOH; NH_4^+; NO_2^-; NO_3^-; Al_2O_3; $Al(OH)_3$; dye pigments. 2. Remain in landfill through incorporation into microbial protoplasm: NH_4^+; C; P; S; K. 3. May escape into atmosphere: CO_2; CH_4; volatile short-chain fatty acids; H_2S; mercaptans; N_2; NH_3.	1. At present, largely a water pollution problem. 2. Some low molecular weight hydrocarbons; polynuclear and aromatic hydrocarbons may be carcinogenic. 3. Acrolein; S-oxides; CO; H_2S; phenol are irritants and/or toxicants. 4. H_2S and mercaptans produce odor nuisance. 5. Phenols produce taste and odor in water. 6. Particulate matter reduces clarity of air. 7. Asbestos fiber produces pulmonary damage, including cancer.	1. Study of amounts now entering into landfills and incinerators, and which will do so as water pollution regulations are tightened to judge health significance of this type of wastes. 2. Expansion of ongoing studies on rates and amounts of travel of the full spectrum of ions introduced into a landfill either directly or by way of decomposition of textile mill wastes.
		PAPER MANUFACTURE (100 lb waste/ton Product)			
Sulfite Digester liquors Process chemicals Kraft Digester liquors Process chemicals Ground Wood Paper Mills Fine bark and wood particles White water	Na sulfide, NaOH, Na sulfate, Na carbonate, Ca bisulfite, Na lignate, cellulose (6.7%), SO_2, ligno sulfonic acid (65%), reducing sugars (20%), sugar-sulfur-dioxide derivatives (8.4%), calcium, volatile acids, alcohols, acetone, furfural Na_2SO_4, $NaCO_3$, NaOH, cellulose lignins (50%), reducing sugars (20%), SO_2, volatile acids, alcohols, acetone, furfural, Na lignate Cellulose (50%), lignin (25%), pentosans (20%) Fixed Solids (11.9%). Lime mud ($CaCO_3$), wax, starch, resins, asphalt, alum, clay, titanium dioxide, zinc sulfide, talc, calcium sulfate, dyes Volatile Solids (88.1%). Fiber-cellulose, sugars, complex polysaccharides, protein, volatile acids, alcohols, ketones, aldehydes	1. Stack discharges: See Items 1, 2, 3, and 4, TEXTILE MILL WASTES (above). 2. Appear as mineral compounds or metals in ash to landfill: $CaCO_3$; CaO; $Ca(OH)_2$; Al_2O_3; $Al_2(SO_4)_3$; TiO_2; Ti_2O_3; $ZnSO_4$; ZnS; $CaSO_4$.	1. Possible leachates to groundwater: See Item 1, TEXTILE MILL WASTES (above); plus Ti-oxides; carbonates. 2. See Item 2, TEXTILE MILL WASTES (above). 3. See Item 3, TEXTILE MILL WASTES (above); plus H_2S; mercaptans.	1. At present mostly a water pollution problem. 2. See Items 2, 3, 4, and 5, TEXTILE MILL WASTES (above).	1. See Items 1 and 2, TEXTILE MILL WASTES (above); applicable also to paper manufacture wastes.

TABLE 25 (Continued)

1	2	3	4	5	6
		LEATHER PRODUCTS			
Scrap leather Leather dust Wastes from skin cleaning Dyes, oils, processing wastes	Collagen (85%), lipids, albumins, globulin, carbohydrates Collagen (nitrogen - 5%-12%) Soil, NaCl; nonfibrous protein; blood; fats; hair; manure Precipitated lime, NaCl, sulfides, chromium, high volatile solids, $CaCO_3$, K_2O, Fe	1. Stack discharges: See Items 1, 2, 3, and 4, TEXTILE MILL WASTES (above). 2. Appear as mineral compounds or metals in ash to landfill: NaCl; $CaCO_3$; $CaSO_4$; Cr; Cr_2O_3; K_2O; FeO; F_2O_3.	1. Possible leachates to groundwater: except for absence of tin salts, See Item 1, TEXTILE MILL WASTES (above); plus NaCl. 2. See Item 2, TEXTILE MILL WASTES (above). 3. Same as Item 3, TEXTILE MILL WASTES (above); plus H_2S; mercaptans.	1. See Items 2, 3, 4, 5, and 6, TEXTILE MILL WASTES (above). 2. Cr either as metal or in combined form constitutes a toxicological hazard ("heavy-metal poisoning") if leached into the groundwater.	1. Items 1 and 2, TEXTILE MILL WASTES (above) applicable also to LEATHER PRODUCTS.
		PETRO-CHEMICAL			
Synthetic Fiber Manufacture Polymerized hydrocarbons Chemicals Paving and Roofing Materials Asphalt; tars; felt; asbestos; paper; cloth; fiber Rubbers and Plastics Scraps from molding, extrusion, finishing Coagulated rubber Semipolymerized materials General wastes Spent catylist, filter materials, soot, tar, resins	Synthetic polymeric amides with many acrylic units, chlorinated hydrocarbons, cellulose, cellulose-acetate Sulfides, polysulfides, acrylonitrile, alcohols, ketones Hydrocarbon polymers, sulfonated polymers, chlorinated hydrocarbons Butadiene, styrene Lime solids, caustic soda, sodium sulfide, chromium oxides, coke, aluminum chloride, acrolein	1. Appear in stack discharge as products of synthesis and incomplete combustion: HCl; halides; aldehydes; low molecular weight hydrocarbons; low molecular weight polynuclear and aromatic hydrocarbons; phenols; acrolein. 2. Appear in stack discharge as products of combustion: CO; SO_2; S_2O_3; SO_3. 3. Appear in stack discharges as by-products of discharge: N-oxides. 4. May appear as particulate matter in stack discharge. 5. Appear as mineral compounds in ash to landfill: $Ca(OH)_2$; $CaCO_3$; NaOH; Na_2CO_3; NaCl; $Al(OH)_3$; Al_2O_3; Na_2SO_4; CrO_2; CrO_3; AlCr..	1. May leach to groundwater: CO_2; aldehydes; organic acids; phenols; sulfides and sulfates; chlorinated, low molecular weight, polynuclear, and aromatic hydrocarbons; NH_4^+; $Ca(OH)_2$; $CaCO_3$; NaCl; Na_2SO_4; Al_2O_3; $Al(OH)_3$; Na_2SO_3; CrO_2; CrO_3. (Biological breakdown slow and very limited.) 2. See Item 2, TEXTILE MILL WASTES (above). 3. May escape to atmosphere: CO_2; Ch_4; H_2S; mercaptans; N_2; NH_3. (Although possible - not likely.) 4. These wastes would not be composted.	1. See Items 1 to 7, Column 5, OIL REFINERY WASTES (above).	1. Items 1 and 2, OIL REFINERY WASTES (above) applicable also to PETRO-CHEMICAL wastes.

TABLE 25 (Continued)

1	2	3	4	5	6
CHEMICAL PRODUCTION WASTES					
Fertilizers Sweepings; dust; discard; spills; clays; slimes; tallows; containers	Nitrogen, phosphorus, potassium, H_2SO_4, sulfur, silca; fluoride	1. Appear in stack discharge as combustion products: CO_2; S-oxides; P-oxides. 2. May appear in stack discharge as products of incomplete combustion or synthesis: chlorinated hydrocarbons; organo-phosphorus compounds; aldehydes; phenols; cyano-compounds; HCl; CO; acrolein. 3. Appear in stack discharge as products of incomplete combustion: N-oxides. 4. May appear in stack as a vapor: Hg; Cd; As; Zn; C_2N_2. 5. May appear in stack discharge as particulate matter: chlorinated hydrocarbons; organo-phosphorus and sulfur compounds; oxides of Pb, As, Hg, Mn, Cd, Be, Fe, Zn, Ti, Sb, Si, Cu, Ba, and Mg. 6. Appear in slag and ash for disposal in landfill: compounds listed under Items 4 and 5.	1. May leach to groundwater: CO_2; aldehydes; organic acids; phenols; chlorinated hydrocarbons; organo-phosphorus and sulfur compounds; cyano-compounds; phenols; sulfides; sulfites; sulfates; NH_4^+; NO_2^-; NO_4^-; phosphates; $MgSO_4$, $FeSO_4$, and $CaSO_4$ in acid sludges; Zn, ZnO, $PbCrO_4$, MgO, CdO, in acid water; TiO_2; $al(OH)_3$; As compounds. 2. Remain in landfill as microbial protoplasm: NH_4^+; P; S; K. 3. May escape into atmosphere: CO_2; CH_4; volatile short-chain fatty acids; H_2S; mercaptans; N_2; NH_3.	1. See METALS, Table 24. 2. See OIL REFINERY WASTES (above). 3. Many noncombustible chemicals (Column 2) are toxic in even minute concentrations. Possibility of discharge to atmosphere with stack gases is potential health hazard. 4. Many of products of partial combustion (Column 3) are toxic in trace amounts. Discharge to atmosphere constitutes a possible health hazard. 5. Some products of complete combustion (e.g., metal oxides) are known to be toxic. 6. Dangerous oxides of metals may be transferred to landfill where leaching to groundwater may occur. (Chemical production wastes would presumably not be combined with organic wastes for composting.)	1. Studies to determine present methods of disposal of chemical production wastes and the environmental fate of materials in order to evaluate health implications. 2. Studies to determine the relative amounts of hazardous material from chemical production and other sources in order to evaluate the feasibility of combining all types of wastes in a single community or regional wastes management project. 3. Studies of the spectrum of chemical wastes and of the health significance of individual fractions in order to determine how they should be managed for environmental goals.
Pesticide Manufacture Chlorinated hydrocarbons	Toxaphene, benzeine, hexachloride, DDT, aldrin, endrin, lindane, dieldrin, chlordane				
Organic-phosphorous compounds	Parathion, malathion, phosdrin, tetraethyl pyrophosphate				
Miscellaneous organic compounds	Carbonates, dinitrophenols, organic sulfur compounds, organic mercurials				
Inorganic compounds	$CuSO_4$; $Pb_2As_2O_7$; chlorides and fluorides; Zn_3P_2; thallium sulfate; sodium fluoracetate				
Explosives TNT, TNT isomers, organic acids	Volatile acids				
Metals	Copper, zinc				
Oils, soaps, chemicals	SO_2, $FeSO_4$, $Na_2S_4O_7$, hydrosulfides, nitrogen, toluene, HNO_3.				
Miscellaneous Processing Wastes Particulate clouds and dust	CS_2; Cl_2; HCN; HCl; metallic compounds of Pb, As, Hg, CN, Mn, Cd, Be, Fe, Zn, and their oxides				
Pigments	TiO_2; Pb; $PbCrO_4$; Zn; Ba; Sb (antimony); Fe; Cl				
Extenders	SiO_2; Ca, Ba, and Mg carbonates; silicates; clays				
Contaminated activated carbon	Organic pesticides; carbon				
ENERGY PRODUCTION					
Chemicals used in Cleaning Boilers	Trisodium phosphate; sodium carbonate; sodium; hydroxide; Na sulfite; $NaNO_3$; detergent	1. Except for maintenance debris, not subject to incineration. For products of incineration of maintenance debris, see Table 24, PAPER, WOOD, and OIL REFINERY WASTES (above).	1. May leach to groundwater: Na_2CO_3; trisodium phosphate; NaOH; Na_2SO_3; $NaNO_3$ detergent; Fe-oxides; $Ca(OH)_2$; $CuCO_3$; Al_2O_3; $Al(OH)_3$; $Mg(OH)_2$; $MgCO_3$. 2. In presence of sufficient available C and N, remain in fill through incorporation into microbial protoplasm: NO_3^-; P; C; S. 3. In presence of sufficient available C and N, may escape to atmosphere: CO_2; CH_4; N_2; NH_3; H_2S. (The disposal of fission wastes is a responsibility of the A.E.C.)	1. Principal health hazards of energy production are not controllable by solid wastes management procedures: air pollution and radioactive wastes most important problems 2. Solid wastes implications are largely related to leaching of mineral compounds from clinker and ash from coal-burning furnaces. This may be a very important local water quality problem. 3. Amount of health-related pollutants resulting from incineration of maintenance wastes (Columns 1 and 2) not sufficient to be significant.	(Health-related research needs not particularly relevant to solid wastes management.)
Air Pollution Control Residue Fly ash	Fe oxides; silica; C; CaO; Al_2O_3				
Particulates Cinders (ash, slag)	C; Fe; Fe oxides; Fe sulfates; MgO; $Mg(OH)_2$; Si; SiO_2; unburned coal				
Maintenance Wastes Oily rags	Cotton fibers, machine oil				
Oil-soaked sawdust	Wood, machine oil				
Oil-soaked shavings					
Coal Preparation Wastes	Coal; shale; clay; sandstone; calcite; gypsum; kaolin				
Wastes from Atomic Power Plants	Fission products; uranium; plutonium; SiO_2; traces of Fe, Ni, Cr, Al, and Hg				

TABLE 25 (Continued)

1	2	3	4	5	6
PRIMARY METAL MANUFACTURE					
Steel Blast furnace and precipitator residue Slag, ore, limestone, mill scales Tar, coke dust Pickling liquor residues Oils Nonferrous Metal Copper, aluminum, lead, zinc, nickel, magnesium, antimony Brass Machine wastes and scrap metal Pickling liquor residues Iron Foundry Moldings Core sands Fly ash Coal Lime, alum, NaOH, slag	[Fe oxide (70%), silica (12%) alumina, carbon, lime, magnesia, phenol benzene] Fe and Fe oxides Cyanogen, $(NH_4)_2(SO)_4$ - $Fe(SO)_4$ (Na_2CO_3 from phenol recovery $SO_4^=$, acid sulfates, ferrous hydrates from pickling liquor treatment) Copper (66%), zinc (33%), tin and lead (tr.) (H_2SO_4, Cu, Zn, Cr, hexavalent Cr, Fe) Clay, sea coal, sand (85%) (Carbon, Fe, Al, Ca, Mg, Si, S, Ti, P)	1. Appear as mineral compounds or metals in ash to landfill FeO, Fe_2O_3, SiO_2, Al_2O_3, Fe, CrO_2, CrO_3, Cu_2O, CuO, PbO, CaO, Na_2CO_3, $Fe(OH)_2$, $Fe(OH)_3$, ZnO, Cu, SnO, clay, sand, Al, Ca, Mg, Si, Ti, MgO, P_2O_5, etc. 2. May appear as particulate matter in stack: (See 1 above). 3. May appear as vaporized metal in stack discharges Zn, Pb. 4. May appear in stack gases: SO_2, SO_3, CO, CO_2, C_2N_2. 5. Appear as stack gases as by-products of incineration process: N-oxides. Note: Incineration of metal manufacture wastes not common.	1. Remain in landfill as inert or relatively inert compounds or uncombined metals unless eroded by surface runoff: a. (See Item 1, Column 3.) b. Lime, slag, ore, coke dust, sand, fly ash, coal, brass, metal scrap (See Column 1). 2. May leach to groundwater: acid sulfates; limestone, Fe, Na_2CO_3.	1. Particulate lead in air may cause chronic intoxication; soluble lead compounds are cumulative toxins. Amount may be significant in lead processing wastes. 2. Inhalations of zinc fumes or finely divided zinc oxide may result in "metal fume fever" and damage to respiratory tract. Amount may be significant in zinc processing wastes. 3. CO, and oxides of sulfur and nitrogen are toxicants and/or irritants. 4. Compounds of Cr toxic. Cr, Ni, etc., may produce cancer. Hazardous even in small amounts.	1. Study of amount of metal manufacturing wastes going into incinerators and to landfills to judge health significance of this type of solid wastes. 2. Study of future status of industrial wastes in overall problem of regional solid wastes management.
METAL FINISHING					
Acids Metals Cyanides Alkaline cleaners	H_2SO_4, HCl NaOH NaCN, KCN Cr, Zn, Cu, Ni, Sn, phosphates, silicates, carbonates, pond and chemical precipitation sludges from wastes treatment	1. Incineration of metal finishing wastes not practiced. If incinerated, conversion products, etc., as primary metal manufacture (above).	1. Probably remain in landfill as relatively inert materials: insoluble metal salts, e.g., silicates and carbonates. 2. May leach to groundwater: if metal finishing wastes in domestic refuse fill: bicarbonates, phosphates, $CaSO_4$, $MgSO_4$, Fe_2SO_4, $BaCr_2O_7$, FeO, ZnO, CuO, SnO. 3. May leach to groundwater if in separate fill: Na_2SO_4, NaCl, $CaSO_4$, $FeSO_4$.	1. Public health significance of metal plating wastes disposal not fully identified. 2. Metallic oxides soluble in acid water of refuse fill (See Item 2, Column 4) are toxic. See Item 4, PRIMARY METAL MANUFACTURE (above).	1. Study of nature and amount of metal finishing residues which might be combined with other refuse in a regional solution to overall solid wastes management by incineration or landfill.
OIL REFINERY WASTES					
Caustic sludges Acid sludges Grease and oil residues Free and emulsified oil Tank bottom sludge Coke Wastes catalyst Filtering clays Asphalt and tars Chemicals from by-product manufacturing Traces of metals	Organic sulfur compounds H_2S, organic acids mercaptans SiO_2, $Al_2(SiO_3)_3$, S, Pb, tetraethyl lead, PbS, $CaSO_4$, $CaHPO_4$, H_2SiO_3, $Al(OH)_3$, polymers, organic esters; miscellaneous sulfur compounds; miscellaneous emulsions	1. Appear as in stack discharges: SO_2; SO_3; CO; CO_2; PbO; low molecular weight hydrocarbons; low molecular weight aromatic and polynuclear hydrocarbons; mercaptans; phenols; aldehydes; ketones; SiO_2; Al_2O_3; Pb. 2. Appear as solids in incinerator ash to landfill, SiO_2, $Al_2(SiO_3)_3$, $Al(OH)_3$, $CaSO_4$, $CaHPO_4$. 3. Appear in stack discharge as by-products of incineration process: N-oxides.	1. Solids in ash from incinerator (Item 2, Column 3) remain in landfill as inert materials as do filtering clays and various by-product sludges. 2. H_2SO_4, caustics, lead salts, and phenols may leach from landfill to groundwater. 3. Oil residues, solvents, etc., may contaminate groundwater.	1. Chlorinated hydrocarbons may damage central nervous system. 2. Aldehydes, ketones, oxides of sulfur, CO, H_2S, oxides of nitrogen are irritants and/or toxicants. 3. Some low molecular weight polynuclear hydrocarbons are carcinogenic. 4. H_2S and mercaptans produce odor nuisance. 5. Particulate matter reduces clarity of atmosphere. 6. Lead salts have cumulative toxic effect on man. 7. Phenols produce taste and odor in water.	1. If oil refinery wastes are to be incinerated with domestic refuse, animal manures, and demolition debris, studies of technology necessary to preclude health hazards are needed. 2. Studies are needed to evaluate the long-term biodegradation of refinery wastes in sanitary landfills, and the problem of maintaining their isolation from water resources.

TABLE 25 (Continued)

1	2	3	4	5	6
METAL FABRICATION*					
Transportation Equipment Machinery, Fabricated Metal Products Metal scraps from extrusion, drilling, milling, machining, and grinding Miscellaneous wastes from product finishing	1. Ca; Cr; hexavalent Cr; Al; Fe; Cu, Ti; brass; Sn; Zn; cast iron.	1. Metal scrap not normally to incinerator; otherwise See METALS, Table 24.	1. Appear as inert metals in landfill, if not incinerated. Otherwise, See METALS, Table 24.	1. See METALS, Table 24.	1. Study needed to determine amounts of metal fabrication wastes in total solid wastes of community, and present disposal methods in order to evaluate health implications.
	2. Plastics, synthetic and natural fiber cloth, rubber, wood.	2. See PLASTICS, CLOTH, WOOD, RUBBER, Table 24.	2. See PLASTICS, CLOTH, WOOD, RUBBER, Table 24.	2. See PLASTICS, CLOTH, WOOD, RUBBER, Table 24; also OIL REFINERY WASTES (above).	
	3. Ceramics, slag, sand, abrasives.	3. Appear unaltered in ash.	3. Appear in landfill as inert materials.	3.	
	4. Paint, adhesives, solvents, resins, lubricants.	4. See Item 1, Column 3, OIL REFINERY WASTES (above). Also WOOD PRODUCTS (below).	4. See Item 3, OIL REFINERY WASTES (above).	4. See OIL REFINERY WASTES (above).	
	5. Pickling liquor residues.	5. See PRIMARY METAL MANUFACTURE (above).	5. See Item 2, PRIMARY METAL MANUFACTURE (above).	5. See PRIMARY METAL MANUFACTURE (above).	
(*Item numbers in Columns 3, 4, and 5, correspond to those in Column 2.)					
WOOD PRODUCTS MANUFACTURE*					
Processing Wastes Residues from sawing, drilling, shaping, planing, and sanding operations Finishing Wastes Residues from painting, gluing, upholstering operations	1. Sawdust, shavings, drillings, scrap lumber, containing lignin, and cellulose (nitrogen 0.12%; P_2O_5 0.002%; K_2O 0.15%).	1. See WOOD, Table 24.	1. See WOOD, Table 24.	1. See Table 24, WOOD, CLOTH, PAPER, PLASTICS, RUBBER, METALS.	1. Analysis of incinerator stack discharges needed to determine amounts and types of gases, metals, and particulates of other types, resulting from incineration of wastes from manufacturing involving wood and related products cited, under various conditions of operation and by-product control.
	2. Cloth, paper, plastics, foam rubber, synthetic and natural fibers.	2. See CLOTH, PAPER, PLASTICS, RUBBER, Table 24.	2. See CLOTH, PAPER, PLASTICS, RUBBER, Table 24.	2. Also PRIMARY METAL MANUFACTURE and OIL REFINERY WASTES (above).	2. On the basis of Item 1 (above), an evaluation is needed of the extent of health hazard attributable to the wastes of wood using industries disposed of by incineration.
	3. Paint, varnish, adhesives, solvents, pigments (TiO_2; PbO; Pb_3O_4; ZnS; $PbCO_3 \cdot Pb(OH)_2$; BaS; FeO; CdS; chrome green).	3. May appear in ash to landfill: (See Items 3, Column 2). May appear in stack discharges as particulates (See Items 3, and 4, Column 2). May appear in stack discharges as gas: ZnS; Zn; SO_2; SO_3; Pb; Ba; CO; CO_2; Ti; Cr; Cd.	3. May leach to groundwater, ZnO, FeO, Fe_2O_3, $CaCO_3$, $MgCO_3$, etc., in acid (H_2CO_3) water.		
	4. Extenders (SiO_2; $CaCO_3$; $BaCO_3$; $MgCO_3$).	4. May appear in ash to landfill or as particulates in stack discharges.	4. May remain in fill as inert compound.		
	5. Solvents (e.g., linseed oil; turpentine; tung oil; petroleum fractions).	5. See Item 1, Column 2, OIL REFINERY WASTES (above).	5. May contaminate groundwater.		

(* Item numbers in Columns 3 and 4 correspond to those in Column 2.)

TABLE 25 (Continued)

1	2	3	4	5	6
STONE, CLAY, AND GLASS PROCESSING*					
Abrasives Earth Materials	1. Finely divided iron and glass. 2. Cement, clay, ceramics, gypsum, asbestos, stone, paper.	(If added to combustible material in an incinerator.) 1. Appear as inert materials in incinerator ash to landfill. 2. Appear as particulates in stack discharges	1. Appear as relatively inert materials in landfill or compost. 2. Fe_2O_3 and $CaCO_3$ may leach to groundwater with acid (H_2CO_3) water.	1. Asbestos fibers in atmosphere seriously and permanently injure lung tissue. 2. Silicosis results from inhalation of abrasives, glass, and stone particles, hence is an occupational hazard of stone and glass, processing workers. Asbestos fibers cause pulmonary damage, including cancer.	1. Investigations of methods of preventing asbestos fibers from being discharged from incinerator stacks, as well as of fate of asbestos in incinerators, is needed.
(* Item numbers in Columns 3, 4, and 5, correspond to those in Column 2.)					
PRINTING AND PUBLISHING*					
Paper trimmings Binding residues	1. See PAPER, Table 24. 2. Metal wire and staples, cloth scraps, glue.	1. (See PAPER, Table 24.) 2. Appear as inert residues in ash to landfill.	1. (See PAPER, Table 24.) 2. Fe_2O_3 and $CaCO_3$ may leach to groundwater with acid (H_2CO_3) water.	1. (See PAPER, Table 24.) 2. See CLOTH, Table 24. (Paper probably only fraction of sufficient magnitude to have public health implications.)	(See PAPER, Table 24.)
(* Item numbers in Columns 3, 4, and 5, correspond to those in Column 2.)					

TABLE 26

Source 1	Type 2	Environmental Fate of Material and Conversion Products in Relation to Disposal Method		Identified Public Health Significance [at present (1968) stage of project] 5	Suggested Research Needs 6
		Incineration 3	Sanitary Landfill and Composting 4		
		MANURE			
Cattle Manure (**Average**: 10.44 lb/1000 lb cow-day; 18% total solids; 14.4% volatile solids) (C:N, 11.5)	Lignin (20%); cellulose (25%); hemicellulose (18%); fatty and other volatile acids (3.2%)(includes butyric, valeric, and caproic acids); protein, protein-diamines, NH_4, organic N-intermediates (total N, 3.79%); P_2O_5 (1.1%); $CaCO_3$. Pathogens (not necessarily present) Salmonella; Mycobacterium bovis; Brucella caburtus; Leptospira; E. coli; viruses.	1. Stack discharge: See Table 24, under WOOD, Column 3, Items 1, 2, 3, and 4. 2. Appear in ash for disposal to landfill: K_2O; KOH; phosphates.	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus sulfates; phosphates; carbonates. 2. Possible transport to groundwater: pathogenic organisms in the manures. These may be killed during composting. 3. May escape into atmosphere: CO_2; CH_4; volatile short-chain fatty acids; H_2S; mercaptans; N_2; NH_3. (N_2 and CH_4 formation unlikely in composting.)	1. Fly nuisances and danger of fly borne disease is a major public health concern with manure. 2. Odor nuisance of manure an important environmental factor. 3. Leaching of nitrogen may lead to dangerously high NO_2^-, and NO_3^- levels in the groundwater. 4. Contamination with leachates from stored manures can be major source of groundwater pollution.	1. Continuation and expansion of ongoing research on the nature and extent of groundwater contamination by leachate from stored manure. 2. Continued technological research on improved systems for managing animal wastes.
Swine Manure (**Average**: 0.795 lb/100 lb pig-day; 19% total solids; 15% volatile solids)	Lignin; cellulose; hemicellulose; protein, protein-diamines, NH_4, organic N-intermediates (total N, 5.4%); fatty and other volatile acids (5.8%); P_2O_5 (4.6%); K (2.1%); $CaCO_3$. Pathogens (not necessarily present) Salmonella; Brucella suis; E. coli; viruses.				
Poultry Manure (**Average**: 0.20 lb/5 lb bird-day; 23% solids; 18% volatile solids) (C:N, 7.5)	Lignin; cellulose; hemicellulose; protein, protein-diamines, NH_4, organic N-intermediates (total N, 5.4%); fatty and other volatile acids (5.8%); P_2O_5 (4.6%); K (2.1%); $CaCO_3$. Pathogens (not necessarily present) Salmonella; E. coli; viruses.				
Sheep and Goats (Total solids, 25%)	Lignin (22%); cellulose (19%); hemicellulose (18.5); protein, protein-diamines, NH_4, organic N-intermediates (total N, 4.0%); fatty and other volatile acids; P (1.5% as H_3PO_4); K_2O (1.9%); $CaCO_3$. Pathogens (not necessarily present) Salmonella; Brucella melitensis; E. coli; Leptospira; viruses.				
Horse Manure (Total solids, 25%-30%)	Lignin (14%); cellulose (28%); hemicellulose (23.5%); proteins (7%), protein-diamines, NH_4, organic N-intermediates (total N, 2%); P (5% as H_3PO_4); K_2O (1.5%); $CaCO_3$.				

TABLE 26 (Continued)

1	2	3	4	5	6
PRUNINGS (1.5-2.0 ton/acre-yr)					
Orchards and Groves Apple Apricot Cherry Peach Pear Plum Citrus Walnut Miscellaneous fruits Vineyards	Leaves and wood (cellulose, 55%; lignin, 24%; pentosans, 18%; nitrogen, 2%)	1. Stack discharge, ash residue, See Table 24, under WOOD, Column 3, Items 1, 2, 3, and 4. 2. See Item 2, MANURE (above).	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2. 2. Possible migration or transfer to adjacent area: plant pathogens. 3. See Item 3, MANURE (above).	1. Major present significance is in the heavy air pollution resulting from open burning. 2. See Table 24, under WOOD, Column 5, Items 3, 4, and 5.	1. Continuation and expansion of ongoing research on technology of disposing of these wastes inexpensively, yet in an acceptable manner. 2. Continuation of research on effect on soil brought about by incorporation of ground material in the soil, and on the survival of plant pathogens thus introduced
CHEMICALS					
Field Crops Corn stalks Wheat and other grain stubble Sugar cane stalks bagasse Rice hulls Truck Garden Cull vegetables Vegetable trimmings Cull berries Orchards Cull fruit Green drop Greenhouse and Nursery Vegetable material Flowering plant residue Clay pots Glass Plastic containers	Carbohydrates [(80%)(cellulose and sugars)]: protein and fat (20%); lignin; trace elements Carbohydrates; protein; lignin; trace elements Carbohydrates; protein; lignin; organic acids; trace elements Cellulose; lignin; carbohydrates; trace elements; clay; glass; plastic	1. Stack discharge and ash residue: See Table 24, under WOOD, Column 3, Items 1, 2, 3, and 4. Additional stack discharges: aldehydes, ketones, and acrolein. 2. See Item 2, MANURE (above). 3. Grain stubble and sugar cane stalks usually burned in the field. 4. Clay as inert material to landfill. 5. Plastics: See PLASTICS, Table 24.	1. Possible leachates to groundwater: See Table 24, under WOOD, Items 1 and 2; and GARBAGE, Items 1 and 2. 2. See Items 3, MANURE (above). 3. Clay and plastic are inert.	1. Fly nuisances is a major public health concern with truck garden and orchard residue. 2. Odor nuisances from decaying vegetable and fruit residues an important environmental factor. 3. See Item 1, PRUNINGS (above).	1. Continuation and expansion of ongoing research on technology of disposing of field and orchard crop residues inexpensively, yet in an acceptable manner.
CROP RESIDUES (Field Crop Wastes, 1-4 ton/acre-yr)					
Fertilizer Residues Containers Sweepings and crop residues Dust on prunings Insecticide Residues Containers Crop residues Residue on prunings	Nitrogen (NO_3, 1.6%; NH_4, 8.2%; organic 2.4%) Phosphate (phosphoric acid) (11%) Toxaphene, benzeine, hexachloride, DDT, aldrin, endrin, lindone, dieldrin, chlordane Parathion, malothion, phosdrin, tetraethyl pyrophosphate, diazinow Carbonates, dinitrophenols, organic sulfur compounds, organic mercurials Copper-sulfate, arsonate of lead, Cpds of Cl and Fl, zinc phosphide, thallium sulfate, sodium fluoracetate K_2O (7%); Cl (3.4%); S (5%); Mg (2%); Fe (1.5%)	1. See Table 25, under CHEMICAL PRODUCTION WASTES, Column 3, Items 1, 2, 3, 4, 5, and 6.	1. See Table 25, under CHEMICAL PRODUCTION WASTES, Column 4, Items 1, 2, and 3. 2. In composting: diazinow degrades to oxodiczinow and sulphotepp. (e.g., from an initial concentration of 3.5 ppm to final of < 0.05 ppm); parathion → paraoxon; amino parathion; P. amino phenol; P. nitrophenol (e.g., initial 3.5 ppm, final < 0.5 ppm); DDT → resistant; dieldrin-resistant in continuous procedures; in batch type: breaks down to aldrin; e.g., initial 3 ppm, final 0.2 ppm.	1. See Table 25, under CHEMICAL PRODUCTION WASTES, Column 5, Items 3, 4, 5, and 6. Extent of hazard unknown. 2. Major hazard arises from improper storage and disposition of pesticide containers. Extent of hazard unknown.	1. Studies on: a. Extent of hazards involved in existing handling of pesticide containers. b. Safe, reliable, and inexpensive methods either of decontaminating presticide containers or of disposing of them.

TABLE 26 (Continued)

1	2	3	4	5	6
CANNING (700 ton/avg. plant-yr)					
Fruit Pulp press Peelings Seeds Cull fruit Oils Resins Vegetable Skins Cores Cobs Shells Stalks Trimmings Crates, Cases, Containers Cans Jars, etc.	Cellulose (55%); lignin (25%); PO_4 (as H_3PO_4, 3%); N (2%) K (as K_2O, 4.0%) Plant pathogens Cellulose (60%); lignin (25%); N (2.5%); P_2O_5 (0.7%); K_2O (2.0%); S; Mg; ash (20%); trace metals; pesticide residues Plant pathogens Wood; cardboard Tin; steel; aluminum Glass	1. Stack discharge: See Table 24, under WOOD, Column 3, Items 1, 2, 3, and 4. 2. Appear as relatively inert compounds to landfill: Fe-oxides; Al_2O_3; SnO; glass-slag. 3. See Item 2, MANURE (above).	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus sulfates, phosphates, and carbonates. 2. Transport to groundwater: plant pathogenic organisms in the fruit and vegetable residues. These may be killed during composting. 3. See Item 3, MANURE (above).	1. Fly nuisances and danger of fly borne disease is a major public health concern with cannery wastes. 2. Odor nuisances from decomposing cannery wastes is an important environmental factor. 3. Public health significance of leaching of pesticide residues cannot be determined because of insufficiency of quantitative data. 4. The survival and spread of plant pathogens cannot be ignored in evaluating methods for disposing cannery wastes.	1. Studies on the amounts of pesticides and other toxic substances in cannery wastes. 2. See Item 2, under PRUNINGS (above).
MEAT [Small Plant (no by-products), 50-80 lb/ton processed; Large Plant (by-products), 20-40 lb/ton processed]					
Meat Stockyards Manure Wastes feed Slaughterhouse and Packing Plant Manure Blood Casing Hair Paunch manure Bones Grease Hooves, etc. Heads Feathers	See this column under MANURE (above). Volatile matter (80%-90%); total N (10%); fibrous protein; fatty acids; neutral fat; P_2O_5 (3.5%); K_2O (2.5%); C-14 (17%).	1. Stack discharge: See Table 24, under WOOD, Column 3, Items 1, 2, 3, and 4; plus aldehydes, ketones, acrolein. 2. See Item 2, MANURE (above).	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus phosphates, sulfates, and carbonates. 2. See Item 3, MANURE (above).	1. See Items 1 and 2, CANNING (above). 2. Possibility of survival and spread of animal (and perhaps human) pathogens in landfill operations, and in by-product production. The extent and hence the importance of this environmental hazard is unknown. 3. See Item 3, MANURE (above).	1. Technological research on improved methods for treating meat processing wastes. 2. Survival and spread of animal pathogens in landfills.
ANIMAL CARCASSES (Animal Raising Casualties)					
Beef and dairy herds Sheep flocks Swine herds Horse herds Poultry flocks	Proteins; fats; glycogen; P; and trace amounts of minerals	1. See Item 2, MANURE (above).	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus phosphates, sulfates, and carbonates. 2. See Item 3, MANURE (above).	1. See Items 1 and 2, CANNING (above). 2. See Item 2, MEAT (above). 3. See Item 3, MANURE (above).	1. None indicated.
FISH PRODUCTS					
Entrails Skins Scales	Protein; amino acids; oils; N; P; K (N + P > 7.0%)	1. Stack discharge: See Table 24, under WOOD, Items 1, 2, 3, and 4. 2. See Item 2, MANURE (above).	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus phosphates, sulfates, and carbonates 2. See Item 3, MANURE (above).	1. See Items 1 and 2, CANNING (above).	1. Technological research on improved methods for treating fishery wastes.

TABLE 26 (Continued)

1	2	3	4	5	6
DAIRY					
Milk Residues Whey Containers Wax - coated paper cartons Plastic - coated paper cartons Glass bottles	Proteins; casein; albumin; carbohydrates; lactose; fat; K; P; S See Table 24, under PAPER and GLASS, Column 2	1. Stack discharge: See Table 24, under WOOD, Column 3, Items 1, 2, 3, and 4; under PLASTIC, Column 3, Items 1 and 3. 2. See Item 2, MANURE (above).	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus phosphates, sulfates, and carbonates. 2. See Item 3, MANURE (above). 3. Plastic coated cartons would be relatively inert.	1. See Items 1 and 2, CANNING (above). 2. At present dairy wastes are more of a water pollution problem than of solid wastes management. 3. The disposal of defective and damage containers is not a significant problem, hence its health significance is only slight.	1. None indicated.
BREWERY AND WINERY (Avg. 6000 tons/plant-yr)					
Spent Hops Grains (Culls and Residues) Oats Rye Wheat Corn Rice Grape Pomace Fermented Starches Yeast and Bacterial Biomass	Volatile solids (90%); lignin; cellulose; carbohydrates; N (3%); P (as H_3PO_4, 1%); K (as K_2O, 0.6%)	1. Stack discharge: See Table 24, under WOOD, Items 1, 2, 3, and 4. 2. See Item 2, MANURE (above).	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus phosphates, sulfates, and carbonates. 2. See Item 3, MANURE (above).	1. See Items 1 and 2, CANNING (above).	1. Technological research on improved methods for treating brewery and winery wastes, with special emphasis on production of useful reclamation products.
SUGAR REFINERY					
Beet Wastes and Pulp (Most of the pulp disposed of as livestock feedstuff) Cane Wastes and Pulp Evaporator Residue Steffen House Concentrate Beet Washings	Cellulose; lignin; N (0.4%); P (0.6%); K (as K_2O, 0.6%); Ca; Mg Cellulose; lignin; N; P; K Hexoses; pentoses; sugar fragments; resins; oils; tar; trace elements Betaine; glutamine; assorted amino acids; KOH Soil; pesticide residues	1. Stack discharge: See Table 24, under WOOD, Items 1, 2, 3, and 4. 2. See Item 2, MANURE (above); plus CaO; $Ca(OH)_2$.	1. Leachate to groundwater: See Table 24, under WOOD, Column 4, Items 1 and 2; plus phosphates, sulfates; and carbonates. 2. See Item 3, MANURE (above).	1. See Items 1 and 2, under CANNING (above). 2. Pesticides contained in the beet washings may leach into the groundwater or drain off into surface waters. Extent and public health hazard unknown.	1. Determination of extent of surface and ground contamination by pesticide residue in beet washings. 2. Technological research on: a. disposal or reclamation of steffen house wastes; b. management of concentrates formed in "closed" system beet-wastes treatment.

TABLE 27

PUBLIC HEALTH EVALUATION OF COMMERCIAL WASTES

Source 1	Type 2	Environmental Fate of Materials and Conversion Products in Relation to Disposal Method		Identified Public Health Significance [at present (1968) stage of project] 5	Suggested Research Needs 6
		Incineration 3	Sanitary Landfill and Composting 4		
		LAUNDRY AND DRY CLEANING*			
Paper Boxes and Wrappings Plastic Bags Residues from Dryer Filters	1. Paper, detergents. 2. Polyvinyl chloride, polyethylene acrylate, copolymers. 3. Wool, cotton, silk, linen, synthetic fibers.	1. See Table 24, PAPER, CLOTH, PLASTICS. 2. Small amounts of SO_2, CO_2, CO, and hydrocarbons from detergents appear in stack gases.	1. See Table 24, PAPER, CLOTH, PLASTICS. 2. Small amounts of soluble sulfates, carbonates, CO_2 from biodegradation of detergents in landfill.	1. See Table 24, PAPER, CLOTH, PLASTICS for health significance of products of incineration and landfill. Public health significance of solid wastes from laundry and dry cleaning operations minimal.	1. No specific studies identified.
		(*Item numbers in Columns 3 and 4, correspond to those in Column 2.)			
		WHOLESALE AND RETAIL MERCHANDISE MARKETS			
Paper Wood Plastic Metal Floor Sweepings Damaged Merchandise Cloth Plastics Ceramics and glass Wood Miscellaneous debris	1. Kraft, shredded newsprint, and miscellaneous paper. 2. Crates, excelsior, boxes. 3. Plastic sheeting, styrafoam, broken toys, (polyvinyl chloride, polyethylene, etc.). 4. Steel strappings, wire, nails, etc. Miscellaneous metal products. 5. Wool, cotton, silk, linen, hemp, sisal, synthetic fibers (all types). 6. Dishes, glass, and miscellaneous inert materials. 7. Organic and inorganic dust.	1. See Table 24, PAPER, WOOD, CLOTH, PLASTICS, METAL. 2. Appear in incinerator ash to landfill: most of metal, ceramics, glass and other inert fractions.	1. See Table 24, PAPER, WOOD, CLOTH, PLASTICS, METAL.	1. See Table 24, PAPER, WOOD, PLASTICS, CLOTH, METAL. Note: Customarily a fraction of "Demostic Refuse" as regards disposal, hence contributes to problems cited in Table 24.	1. See Table 24, PAPER, WOOD, PLASTICS, CLOTH, METAL. 2. Studies of feasibility of salvage and recycle prior to mixing commercial and domestic refuse.
		GARAGES AND SERVICE STATIONS			
Metals Oily and Greasy Materials Plastic and Rubber Paper and Other Containers Glass Cylinder Oil	1. Oil and grease cans, tools, nuts, bolts, spark plugs, coils, condensers, miscellaneous auto parts (steel, tin, copper, tungsten, lead, chromium, nickel, aluminum). 2. Oily rags, sawdust, paper. 3. Tires, floor mats, insulated wire, belts, synthetic fibers. 4. Paper boxes, advertising material, maps, absorbent paper. 5. Headlamps and bulbs.	1. See Table 24, RUBBER, PLASTICS, METALS, CLOTH, PAPER. 2. Appear in ash to landfill: metal objects, glass, mineral residues of organic matter, plastics. 3. May appear in stack discharges; oxides of Al, Fe, Cu, Sn; metal particles (Pd, Sn); acrolein, acids, aldehydes, esters, SO_2, SO_3, NO_2, NO_3, alaphatic chains, low molecular weight hydrocarbons. 4. See Table 25, OIL REFINERY WASTES.	1. Mostly inert landfill materials. 2. Mostly unsuited to composting.	1. See Table 24, RUBBER, PAPER, CLOTH.	1. No special needs identified.

TABLE 27 (Continued)

1	2	3	4	5	6
HOSPITALS					
Paper Plastics Ceramics Cloth Glass Metals Drugs Surgical Wastes Laundry Wastes Restaurant Wastes	1. Pharmaceutical containers, office wastes, newspapers, magazines, books. 2. Disposable syringes and instruments, plastic sheets, trays, cups, containers. 3. Cotton bed linen, uniforms, coats, aprons, gauze, bandages, natural and synthetic fibers. 4. Steel needles, blades, hardware (Fe, Al, Cr, Ni). 5. Bottles, glasses, laboratory glassware. 6. Residues of various drugs. 7. Human tissue. 8. [See LAUNDRY WASTES (above).] 9. [See RESTUARANT WASTES (below); (3-65 lb/employee/day).]	1. See Table 24, PAPER, PLASTICS, CLOTH, RUBBER, GLASS. 2. Metals may appear as inert materials in ash to landfill. 3. See Table 24, WOOD, GARBAGE.	1. See Table 24, WOOD, GARBAGE, PAPER, CLOTH, PLASTICS, RUBBER.	1. See Table 24, WOOD, GARBAGE, PAPER, CLOTH, PLASTICS, RUBBER. 2. Public health implications of incineration of drug residues is unknown but seems trivial in amount.	1. Technological studies of efficiency of hospital incinerators. 2. Extension and expansion of studies of health aspects of landfill disposal of hospital wastes. 3. Survey of nature and amounts of hospital wastes and evaluation of feasibility of combining them with other community wastes for disposal.
FOOD MARKETS					
Boxes and Paper Plastics Wood Produce Meat Wastes Ashes and Sweepings	1. Cardboard, kraft bag and wrapping, coated paper, wood (12 to 23 lb/day/employee). 2. Cull fruit, vegetable trimmings (avg 19 lb/employee/day). 3. Meat casings, fat, bones, feathers.	1. See Table 24, GARBAGE, WOOD.	1. See Table 24, GARBAGE, WOOD.	1. Fly and rodent vectors of disease supported by improperly managed landfill containing food wastes. 2. Odor nuisance an important environmental factor in management of food wastes.	1. No special needs identified.

TABLE 27 (Continued)

1	2	3	4	5	6
		RESTAURANT*			
1. Food Residues 2. Fruit and Vegetable Containers Crates Bags Boxes Cans Bottles 3. Dishes and Utensils	1. Cereals and grains; coffee grounds; meat trimmings; fruit; fruit skins and cores; corn cobs; stalks and tops of vegetables; vegetables; egg shells; bones. 2. Wood, cloth, plastic (polyvinyl chloride); kraft paper; absorbent paper; coated paper; cardboard; plastic; steel; tin; aluminum; nickel; glass. 3. Ceramics; glass; plastic; iron; aluminum.	1. See Table 24, GARBAGE, WOOD. 2. See Table 24, WOOD, CLOTH, PLASTICS, PAPER, GARBAGE. 2. and 3. Appear as inert metals in incinerator ash to landfill: Fe; Al; glass; ceramics; stainless steel. May appear in stack discharges; Sn; oxides of Fe and Al.	1. See Table 24, GARBAGE, WOOD. 2. See Table 24, WOOD, CLOTH, PLASTICS, PAPER, GARBAGE. 2. and 3. Acid water from CO_2 in landfill may dissolve iron oxides and leach to groundwater.	1. and 2. See Table 24, GARBAGE, CLOTH, WOOD, PLASTICS, PAPER. Hazard of trichinosis exists if restaurant wastes fed to swine. (Essentially eliminated as public health hazard by current laws regarding feeding of uncooked garbage to swine.) 3. Soluble iron in water might lead to local water quality problem of economic and nuisance import.	See Table 24, GARBAGE, CLOTH, WOOD, PLASTICS, PAPER. Greater detailed knowledge needed of relative contribution of restaurant wastes and other sources to problem cited in Column 5.
		(*Item numbers in Columns 2, 3, 4, and 5 correspond to those in Column 1.)			
		BUILDING MATERIALS AND LUMBER*			
1. Wood Residues Sawdust Shavings Drillings Scrap lumber 2. Roofing Materials 3. Packaging Materials Crates Boxes Packing 4. Miscellaneous Building Material Residues	1. Lignin and cellulose; resins. 2. Occasional scrap containing asphalt, tar, felt, asbestos. 3. Paper; steel strapping and wire; shredded paper; plastic granules; styrafoam; excelsior; wood. 4. Sweepings containing Portland cement; lime (CaO); sand; clay; broken brick, asphalt and plastic floor tile; ceramic tile; sawdust from wallboard, transite; masonite ($CaSO_4$, asbestos, plastics); damaged containers of paint and pigments.	1. See Table 24, WOOD. 2. See Table 25, OIL REFINERY WASTES 3. See Table 24, PAPER, WOOD, PLASTICS. Metals may appear in incinerator ash as inert metals. 4. Appear as inert fractions of incinerator ash to landfill: cement; lime; sand. May appear in stack discharges: SO_2; SO_3; asbestos fiber; CO; CO_2; see also Table 25, WOOD PRODUCTS MANUFACTURE, Item 3, Column 3.	1. See Table 24, WOOD; also, Table 25, WOOD PRODUCTS MANUFACTURE. 2., 3., and 4. See Table 24, PAPER, WOOD, PLASTICS; also Table 25, WOOD PRODUCTS MANUFACTURE. 3. and 4. See Table 25, STONE, CLAY AND GLASS PROCESSING; also Table 24, UNCLASSIFIED FRACTION.	1. See Table 24, CLOTH, WOOD. 2. and 4. Asbestos fiber in atmosphere serious hazard to lung tissue in even small amounts. 3. and 4. See Table 24, PLASTICS, PAPER. (Health hazard from building materials and lumber principally from wood burning, paper, plastics, and metals add to total of such materials in combined refuse, but "Building Material and Lumber" not principal source.)	See Table 25, WOOD PRODUCTS MANUFACTURE. Studies of amounts of various fractions cited needed to assess importance of this category of wastes to overall community total which might be combined for management and disposal purposes.
		(*Item numbers in, Columns 2, 3, 4, and 5 correspond to those in Column 1.)			
		OFFICE*			
1. Paper (including Packaging) 2. Bottles, Pens, Pencils, Typewriter Ribbons, Floor Sweepings	1. 1.5-1.8 lb/employee/day of paper (bond, duplicating, kraft, rag stock, cardboard, coated, books, magazines, pamphlets, newspaper, carbon paper, etc.). 2. Glass, plastic, steel, aluminum, cloth, dirt. (Avg 1.6 lb/employee/day.)	1. See Table 24, PAPER. 2. See Table 24, GLASS, PLASTICS, CLOTH. Metals (Fe, Al) may appear as inert material in incinerator ash.	1. See Table 24, PAPER. 2. See Table 24, GLASS, PLASTICS. (Metals of minor concern.)	1. and 2. See Table 24, PAPER, PLASTICS, GLASS.	See Table 24, PAPER, PLASTICS. None identified specifically with "office" category of wastes.
		(*Item numbers in Columns 2, 3, 4, and 5 correspond to those in Column 1.)			

TABLE 27 (Continued)

1	2	3	4	5	6
NEWSPAPER PUBLISHING					
Paper Office Wastes	See Table 25, PRINTING AND PUBLISHING Carbon ink and ink containers; inked paper; aluminum tubes. [See also OFFICE wastes (above).]	See Table 24, PAPER, also OFFICE (above).	See Table 24 PAPER, also OFFICE (above).	See Table 24, PAPER, also OFFICE (above).	See Table 24, PAPER.
PLUMBING, HEATING, AIR CONDITIONING, ELECTRICAL WIRING					
Metals Scraps Cuttings Insulating Material Demolition Debris Miscellaneous Wastes	Steel, Fe, Zn, Al, Cu, brass, Cd, Cr, Pb. Fiberglass, asbestos, styrafoam, paper. Wood, plaster, cement, asphalt, felt, tar Rubber, plastic, fiber (natural and synthetic), oily wipings.	See Table 24, METALS, PAPER, RUBBER, CLOTH, PLASTICS, WOOD, GLASS. Also see Table 25, PRIMARY METALS MANUFACTURE.	See Table 24, METALS, PAPER, RUBBER, CLOTH, PLASTICS, WOOD, GLASS. Also see Table 25, PRIMARY METALS MANUFACTURE.	See Table 24, METALS, PAPER, RUBBER, CLOTH, PLASTICS, WOOD, GLASS. Glass fibers hazard to lung tissue and may be discharged from incinerator stack, or inhaled by workmen engaged in installation of insulation.	See Table 24, METALS, PAPER, RUBBER, CLOTH, PLASTICS, WOOD, GLASS. Studies to evaluate the amount and relative importance of this category of wastes to community totals in each class.
PAINTING*					
1. Paint and Pigment Containers 2. Brushes, Rollers, and Sheeting 3. Solvents 4. Paint and Pigment Residues	1. Fe, Al, Pb, Zn, Sn, Sb, Cr, Cu, paper. 2. Wood, rubber, steel, natural and synthetic fibers, plastic, cloth, or paper sheeting. 3. Linseed oil, tung oil, turpentine, petroleum fractions, etc. 4. Pigments TiO_2; PbO; Pb_3O_4; $ZnS \cdot BaSO_4$; $PbCO_3 \cdot Pb(OH)_2$; BaS; $PbCrO_4$; FeO; CdS; Sb_2O_3; NH_4; Fe [$Fe(CN)_6$]; "Chrome Green;" Fe_3 [Fe $CN]_2$; $BaSO_4$; Azo organic pigments [R - N = N - ROH, the R's are aromatics]; phthalocyanic [Cu, N, aromatic rings]. Extenders SiO_2; $CaCO_3$; $BaCO_3$; $MgCO_3$; silicates; clays.	1. Metals cited may appear in incinerator ash to landfill. 2. See Table 24, WOOD, RUBBER, PLASTICS, PAPER, CLOTH. 3. See Table 25, OIL REFINERY WASTES (Item 1, Column 2). 4. Pigment chemicals cited may appear in stack discharges as particulates. May appear in stack discharges as gas: ZnS; Zn; SO_2; SO_3; Pb; Ba; CO; CO_2; Ti; Cr; Cd. Extenders may appear in ash to landfill or as particulates in stack discharge.	1. May appear as inert metals in landfill. 2. See Table 24, WOOD, RUBBER, PLASTICS, CLOTH, PAPER. 3. Solvents may contaminate groundwater. 4. May leach to groundwater; ZnO; Fe_2O_3; $CaCO_3$; $MgCO_3$ in acid (H_2CO_3) water.	1. No public health significance if contained in fill. 2. See Table 24, WOOD, RUBBER, PLASTICS, CLOTH, PAPER. 3. See Table 25, OIL REFINERY WASTES. 4. Reduces quality of water generally; Zn is health hazard.	1. No specific study identified. 2. See Table 24, WOOD, RUBBER, CLOTH, PAPER, PLASTICS. 3. See Table 25, OIL REFINERY WASTES. 4. Analysis of incinerator stack discharges needed to determine amounts and types of gases, metals, and particulates of other types resulting from incineration of paint ingredients at various temperatures and conditions of operation. Evaluation of health hazard attributable to presence of paint residues in combined wastes of a community or region.

(* Item numbers in Columns 2, 3, 4, 5, and 6 correspond to those in Column 1.)

TABLE 28

PUBLIC HEALTH EVALUATION OF SPECIAL WASTES

Source 1	Type 2	Environmental Fate of Materials and Conversion Products in Relation to Disposal Method		Identified Public Health Significance [at present (1968) stage of project] 5	Suggested Research Needs 6
		Incineration 3	Sanitary Landfill and Composting 4		
DEMOLITION AND CONSTRUCTION DEBRIS					
Metal Structural shapes Castings Reinforcing bars Cable Nails Sheet metal Plumbing hardware Pipe Tubing Fabricated members Wiring Wood Plywood Lumber Laths Doors Window frames Structural timbers Stumps Trees and trimmings Inert Materials Brick Stone Concrete Wallboard Tile Glass Earth Plumbing fixtures Miscellaneous Paper Roofing Floor covering Insulation	Fe, Al, Cu, Zn, Brass, Pb, steel Lignin and cellulose Ceramics, $CaSO_4$, glass, concrete, stone, brick, plaster, soil, sand Rubber, plastics, glass wool, paper, asbestos, cloth, asphalt, styrafoam	1. Appear as inert material in incinerator ash to landfill: Fe, Al, Cu, steel, Pb, Zn, CaO, brick, stone, slag, concrete ceramics. See Table 24, METALS. 2. May appear in stack discharge: Pb; Zn; CO_2; CO; SO_2; SO_3; N-oxides; asbestos fiber; low molecular weight hydrocarbons and polyunsaturated hydrocarbons; etc. See Table 24, WOOD, PLASTICS, CLOTH, RUBBER.	1. May remain in landfill as inert material: metal objects; Inert Materials (Item 3, Column 1). 2. May leach to groundwater with acid water: Fe_2CO_3; ZnO, etc. See Table 24, METALS.	1. See Table 24, WOOD, CLOTH, RUBBER, PLASTICS, METALS. 2. Asbestos fiber and glass dust are hazard to lung tissue and may be present in incinerator polluted atmosphere. 3. Demolition debris may be aesthetic nuisance if piled on land surface. 4. Surface dumps of demolition debris may harbor rodents, earwigs, and termites thus producing an environmental, if not a public health, hazard.	1. See Table 24, WOOD, CLOTH, RUBBER, PLASTICS, METALS, also Table 25, METAL PRODUCTS MANUFACTURE. 2. Technological studies of ways of salvaging, recycling, or segregating demolition wastes.

TABLE 28 (Continued)

1	2	3	4	5	6
JUNK AUTOMOBILES*					
1. Metals Body, engine, frame, radiator, battery, locks and trim, bumpers, wiring, etc. 2. Nonmetals Upholstery, moldings, tires, mats, insulation, windows	1. Iron and steel (e.g., 3000#) Cu and Cu alloys (e.g., 40#) Lead (e.g., 22#) Zinc alloys (e.g., 80#) Al alloys (e.g., 35#) Cr, Cd 2. Rubber (e.g., 160#) Plastics (e.g., 63.5#) Insulation (e.g., 40#) Glass (e.g., 85#) Cardboard, fiberboard, felt Cloth Paint	1. Not normally subject to incineration. 2. See Table 24, PLASTICS, RUBBER, GLASS, CLOTH, PAPER.	1. Mostly inert in landfill. Bulk usually placed on land surface. 2. See Table 24, PLASTICS, RUBBER, CLOTH, PAPER.	1. Public health significance of metals generally aesthetic nuisance of auto "graveyards." Incineration of old battery cases increases burden of lead in atmosphere. See Table 24, METALS. 2. Products of incineration of nonmetals particularly objectionable because of practice of open burning to facilitate salvage of metal. See Table 24, PLASTICS, RUBBER, CLOTH, PAPER; also Table 25, OIL REFINERY WASTES for health hazards produced by burning.	(Continuation and extension of studies of methods of salvaging junk automobiles without creating a nuisance or health hazard. Little possibility of including this category of wastes in the overall mass of wastes to be managed in a region except in a landfill of generally unlikely proportions.)
SEWAGE SLUDGE*					
Raw Sludge Digested Sludge	1. Plant and animal matter at lowered energy level. Lignin; cellulose; hemicellulose; protein; protein-diamines; organic N-intermediates; bacteria; viruses; inorganic minerals. (See also Table 26, MANURES.) 2. Cellulose, hemicellulose, lignin, and pectic derivatives of proteins and fats; amino acids; carboxyl, phenolic hydroxyl, sulfonate, protein nitrogen products of partial oxidation of organic nitrogenous compounds, nitrates, nitrites, sulfides, phosphates, bicarbonates, K, Mg, Ca, Zn, Cr, Sn, Mn, Fe, Cu, etc.	See Table 24, WOOD, GARBAGE.	1. See Table 24, WOOD; also Table 26, MANURE. 2. Composting may kill pathogens.	1. Public health significance of incineration same as Table 24, WOOD. 2. Bacteria and virus might escape to groundwater if landfill located on fractured rock; health hazard could result from travel of polluted water in fractured or fissured strata. 3. Digested sludge most commonly utilized on land surface. Intestinal parasites, virus, and pathogens might constitute hazard if unsterilized sludge utilized by householders.	Continued and extended research on technology of raw sludge incineration as part of sewage treatment process under conditions acceptable to air pollution control agencies.

(*Item numbers in Columns 2, 3, 4, and 5 correspoud to those in Column 1.)

*Included in "Special Wastes" category because of practice of separate incineration or disposal on land surface.

Discussion

A detailed study of Tables 24 through 28 makes particularly evident the "work sheet" aspect of the undertaking. Some degree of inconsistency is unavoidable, especially in connection with Columns 1 and 2. For example, it is feasible to list in Column 1 of Table 24 the principal discarded objects which have some content of metal, plastic, or wood, etc. To make such a listing in Tables 25 and 27, however, would require a tabulation of thousands of individual items produced by industry or chemistry. Consequently "Source" (Column 1) in some tables is interpreted as types of physical objects and in others as categories of material, sometimes resulting from a particular process. In relation to Column 2 of the tables the limitations of the data can hardly escape the notice of specialists in individual industries. For example, the full spectrum of metals and compounds associated with paint and paint manufacture, or of residues of the petro-chemical industry, certainly exceeds the listing presented in the tables. It is not so certain, however, that anyone can say just which oxides of bivalent metals, or what less obvious compounds, would result from burning the variety of possible wastes combinations under the several controlled and uncontrolled conditions loosely classed as incineration.

To a large degree the lack of quantitative data is due to the dearth of such information in the literature and to the scale of effort which the project herein reported could exert in any one aspect of the study. This scarcity of information should be somewhat reduced by the recently completed nationwide survey conducted by the solid wastes program. Fortunately, it is not necessary to complete the tables in full detail to determine the course of action needed in research on the public health aspects of solid wastes management.

Research Needs. The foregoing limitations of the tables presented underscore the need for two types of studies noted in Column 6 of the tables:

1. An accurate summary of the kind and amounts of individual materials or compounds, which occur in the wastes of each of a vast number of human activities, in terms of the unit of product produced.

2. A study of the nature and amount of conversion products resulting from wastes management processes, particularly incineration.

Both of these, it will be noted, are not strictly public health research concerns. Instead they involve factors of technology, chemistry, process engineering, and operation. The results, however, would make necessary two types of health-related investigations:

1. Medical evaluation of the health significance of some materials, and the level at which they are hazardous.

2. Environmental health studies of the possibility of exposure of man to significant concentrations of harmful materials resulting from solid wastes management practices; and of the measures necessary to preclude that possibility, with due regard to all other hazards of life.

In some cases materials which occur in solid wastes have already been demonstrated as toxic. Thus, elements such as cadmium, lead, beryllium, and other metals, although normally present only in trace amounts, should be thoroughly followed from their entrance into the wastes stream until and including the time of their final disposal. The same should be done of other materials, which, in their pristine state may be innocuous enough, but when subjected to certain treatment processes form toxic substances. Plastics containing chlorine are a case in point. When incinerated, such plastics are converted to volatile chlorine products highly toxic in nature.

A further review of the research needs cited in Column 6 of the tables leads to several conclusions in relation to the role of public health research in solid wastes management.

1. Because disposal of the combined solid wastes of a community has not been undertaken except by landfill, which at best is monitored for surface evidence of nuisance and for vector control, a large research effort is needed to evaluate the nature and amounts of materials and conversion products which might result from community-wide solid wastes management.

2. Many of the components of wastes presently given limited attention by public agencies involved in solid wastes management are known to have health implications and are subject to public health control in other contexts. Consequently it must be assumed that their presence in solid wastes is a matter of public health concern.

3. The urgent needs for research identified in the project herein reported would mostly not exist if health implications were ignored. They do, however, involve a spectrum of scientific endeavor beyond that of the public health specialist, yet the results have little meaning without his interpretation.

4. In view of Items 1, 2, and 3 above, it is finally concluded that at the present time research teams on which environmental health specialists are prominent and active contributors are a particular need of solid wastes management research. Later, the findings of such studies can be expected to identify specific areas for medical and other health-oriented studies *per se*.

Future Work. Obviously the research needs cited represent a long-term conclusive investigative effort, the results of which would fill out the gaps in Tables 24 through 28, and perhaps correct any errors of fact to which these tables are presently subject. A more modest approach could also add to the usefulness of the tables. This would involve a restudy of the tables in the light of a recently completed national survey of solid wastes by the solid wastes program of the Department of Health, Education, and Welfare, together with a more intensive search of the literature and other sources of specialized information concerning industrial and commercial wastes production and products.

VII. ANAEROBIC DIGESTION

INTRODUCTION

The application of anaerobic digestion to materials other than sewage sludge alone is not a new concept in municipal wastes management. Numerous communities have practiced some degree of dual disposal of garbage and sewage for many years as a result of widespread use of the home garbage grinder. This has resulted in a significant reduction of the garbage fraction of domestic solid wastes without disruption of the sewage treatment process. The concept that other organic fractions of the total refuse of a community might also be reduced in volume and stabilized in this manner is, therefore, but one step beyond current practice.

An integral and attractive aspect of this concept is the use of hydraulic transport. Generally, existing sewer systems would be used with the refuse being ground into the sewers at points of origin or at central grinding stations. Certain materials such as metals, brick, and other high density inert materials would have to be excluded, but the greater part of domestic, light commercial, and agricultural wastes could be transported in this manner. Experiments conducted by the Los Angeles County Sanitation Districts demonstrated the efficacy of refuse transport in sewers. The major difficulty encountered in the Los Angeles experiments resulted from the fact that the sewage treatment plant was not designed to accept the added burden of solids reaching it. As one would expect, if refuse were to be transported by way of sewers, existing treatment facilities would have to be expanded in terms of grit removal chambers, primary sedimentation tanks, and increased digester capacity to cope with the higher solids loading.

OBJECTIVES

The studies of solid wastes disposal by anaerobic digestion reported herein involved two major considerations: 1) the efficiency of volume and weight reduction achieved by the process, and 2) the effect on the process of a given wastes material, i.e., retardation of digester performance because of the presence of toxic substances or through the promotion of unfavorable environmental conditions. From the standpoint of practicality of the method the toxicity consideration is of primary importance, since facilitation of solid wastes transport is sufficient justification for grinding to sewers, regardless of whether or not there is the added benefit of solids reduction by the ensuing anaerobic digestion process.

In large metropolitan areas served by several sewage treatment plants, it might be expedient to discharge a disproportionate quantity of solid wastes to one plant. For this reason, experiments were designed to cover the broad range of loading possibilities.

THE INVESTIGATION

Introduction

The effect of a variety of solid wastes on digester performance has been studied to date, including materials such as garbage and paper which are already present to a degree in raw sewage sludge. Here the purpose was to determine loading limitations in terms of sludge-refuse ratio and solids concentration. Other wastes fractions not normal to sewage sludge also were studied during the period covered by this report. These included Monterey pine wood residues and chicken manure. Wood was selected because it is a component of demolition rubble. The manure was combined with paper to investigate the possibility of constructing special digesters intended solely for treating solid wastes, especially the vast quantities of animal manures which are rapidly becoming an urban rather than an agricultural wastes problem. This state of affairs is an outgrowth of the trend toward industrialization of meat, egg, and milk production in or near metropolitan centers. Industrialization involves the heavy concentration of animals in confined areas to maximize production efficiency. In egg production enterprises it is not uncommon for a hundred thousand hens to be in one building, with each hen producing 0.2 pound per day of a highly malodorous and unstable waste.

Investigations by Hart [70] have shown that while dairy manures are digested poorly, chicken manure is readily amenable to the digestion process. Since chicken manure is a nitrogen-rich waste, the possibility of digesting it in combination with a carbonaceous waste, paper pulp, was investigated. Although chicken manure could be treated in conventional sewage treatment plants, its high concentration of water-soluble organics would divert much of the BOD to the liquid stream of the process. Water quality considerations, therefore, dictate the desirability of charging the wastes to a solid wastes digester. Development of an adequate disposal method for handling the paper and chicken manure fractions of solid wastes would go far toward the alleviation of the total refuse treatment problem, since paper constitutes about 50 percent of domestic solid wastes, and chicken manure is one of the more offensive materials to be treated.

Development of Equipment and Procedures

Several modifications were made in the apparatus described in the First Annual Report. The incubator shown in Figure 3 was equipped with new thermoregulator (control shown in top center). Heavy-duty industrial magnets (4 in. by 1 in.) were substituted for the small laboratory magnets attached to the mandrels of the mixing system. This substitution made it possible for the flat-bottom plastic "pigs" (1-gal capcity) containing magnetic stirring bars to be used as effective reactors for mixed-culture digestion (see Figure 4). Mixing was controlled by a repeat-cycle timer set for 1.5 minutes of operation out of each hour. A battery of eight reactors was set up, of which four were equipped for mixing. The four units not equipped for mixing were 1-gal glass jugs. Each reactor was connected by a stainless steel gas line to an individual liquid displacement-type gas collector (see Figure 5), and the four inverted tube gas collectors previously in use were discarded. Advantages gained by these changes included the elimination of gas diffusion through collection tubing, increase in accuracy of gas volume measurements, and improved mixing in reactors.

Preparation of Raw Materials. Materials were prepared in sufficient quantity for an entire experiment and in a manner to facilitate constant loading at a desired volatile solids strength. Preparation of garbage and sewage sludge was as described in the First Annual Report.

The paper source was a bleachable grade of kraft paper pulp used in the manufacture of brown wrapping paper, paper bags, etc. This material, which was supplied by Fibreboard, Inc., is representative of plain paper, i.e., paper not containing newsprint or dye. Moist paper pulp (34.4 percent dry weight) was stored at 2°C in polyethylene bags. Its carbon concentration was 45.6 percent (dry weight), and its cellulose content, 99.8 percent (dry weight).

Air-dried chicken manure obtained from a nearby egg-production ranch was screened to remove feathers and rocks, and then ground to a fine powder in a Waring blender. The powder was packaged in polyethylene bags and stored at 2°C. Chemical and physical analyses of the manure gave the following results:

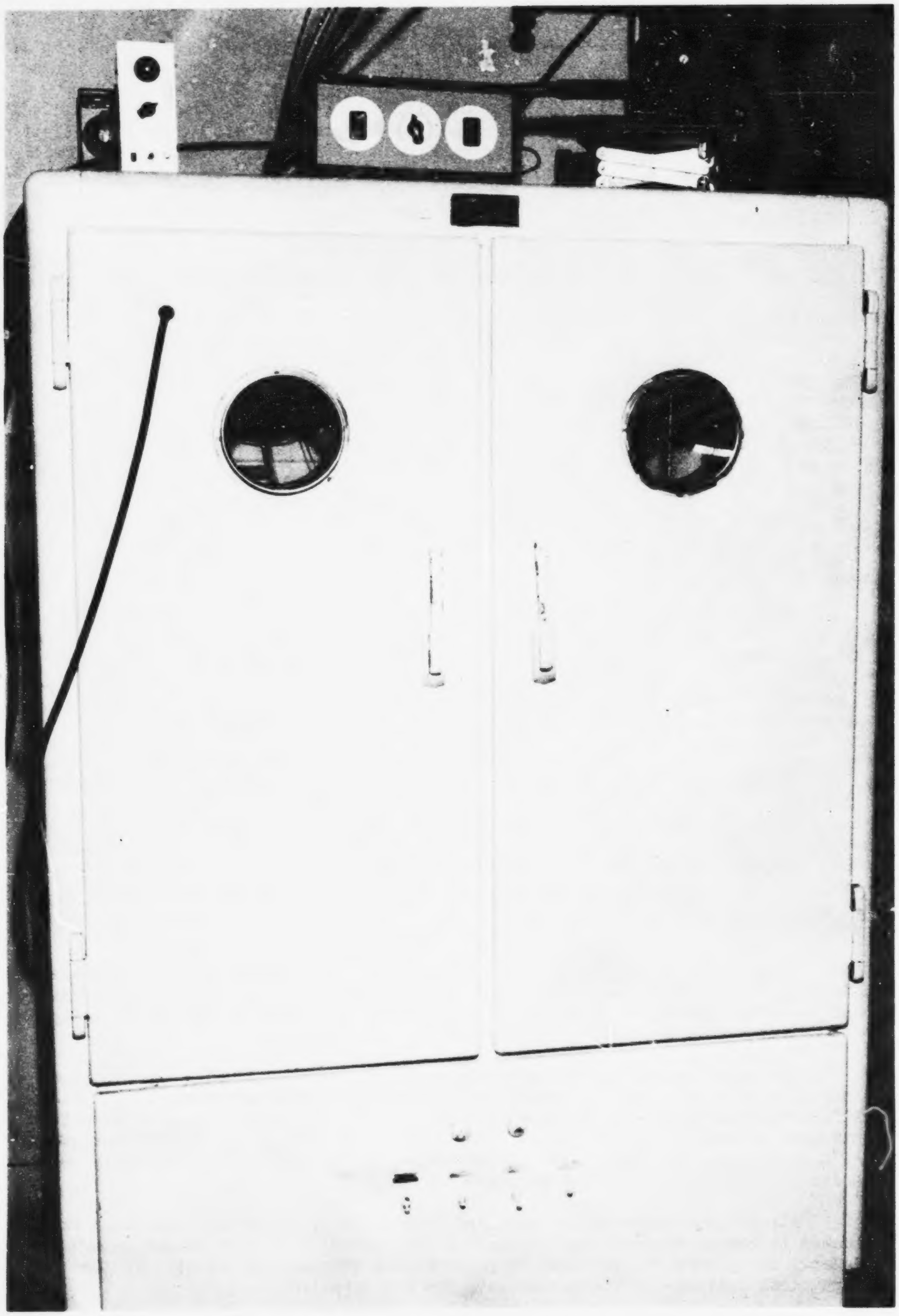

FIGURE 3 . INCUBATOR WITH CONTROLS FOR STIRRING SYSTEM AND TEMPERATURE

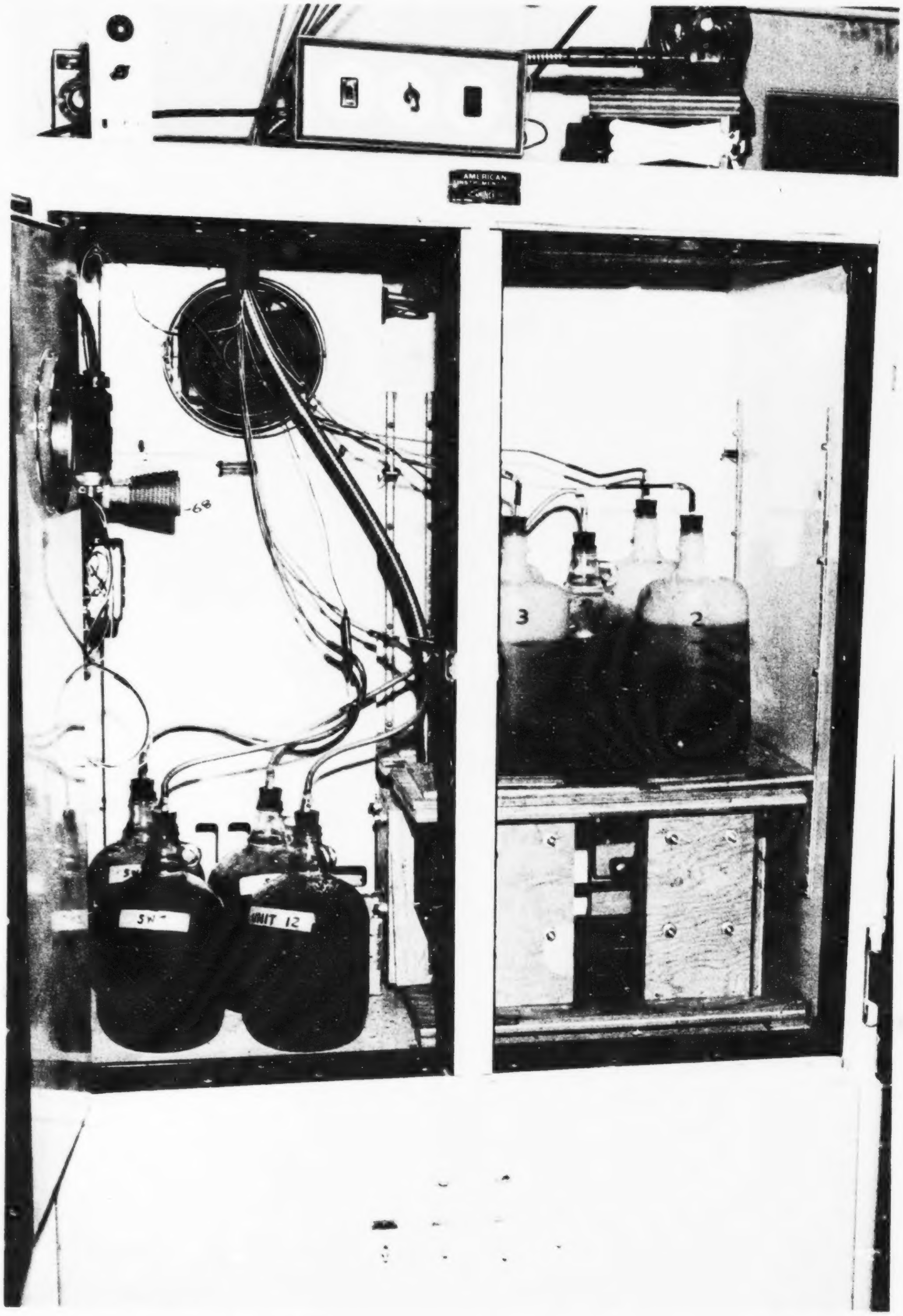
AMERICAN
-68
3
2
SW
UNIT 12

FIGURE 4 DIGESTER UNIT AND STIRRING SYSTEM WITHIN THE INCUBATOR

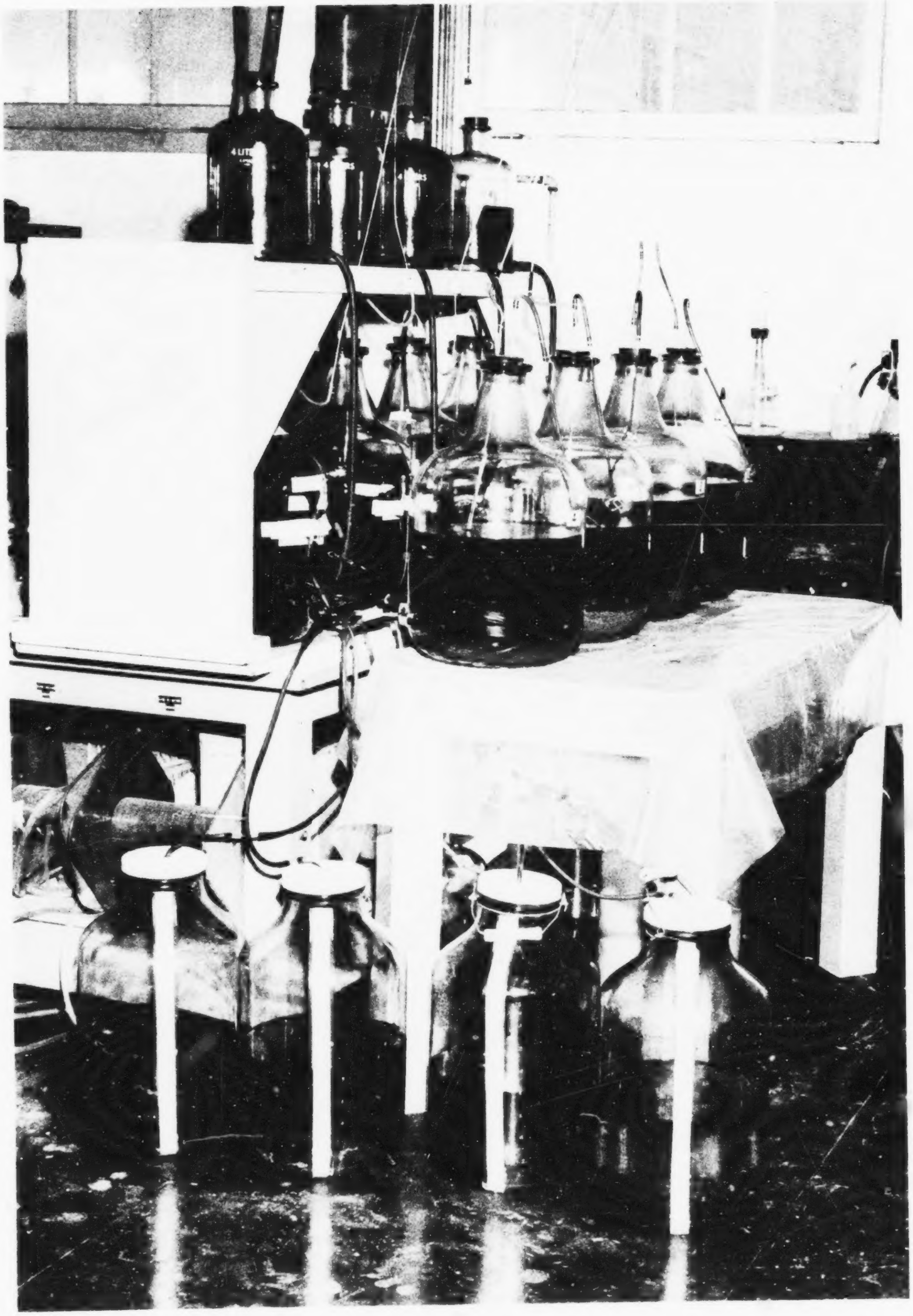

FIGURE 5. DIGESTER GAS COLLECTION APPARATUS

N (dry weight) = 3.2%
C (dry weight) = 23.4%
Moisture = 9.8%
Volatile Solids (dry weight) = 56.2%
Inorganic Material (dry weight) = 43.8%

The unusually high inorganic content reported in the analysis was due to the presence of a large quantity of soil in the manure.

The Monterey pine wood was supplied by the Forest Products Laboratory of the University of California Richmond Field Station. Wood chips obtained from a young tree (containing little heartwood) were ground in a Wiley mill to a fine powder. The powder was stored at room temperature. Analyses of this material gave the following results:

N (dry weight) = 0.07%
C (dry weight) = 50.6%
Cellulose (dry weight) = 80.1%
Volatile Solids (dry weight) = 99.6%
Moisture = 7.14%

Analyses. Total and volatile solids, volatile acids, and alkalinity were measured as described in the First Annual Report. However, the gas analysis procedure was altered by normalizing the methane and CO_2 measurements to 100 percent, and eliminating O_2 and N_2 values. This was done because tests demonstrated that virtually all the air present in the collectors resulted from contamination during feeding and was not a product of digestion. Furthermore, air was expelled from the digesters within ten minutes after feeding, so interference with the digestion process was negligible.

For evaluating properly the fate of added paper and wood materials in the digestion process, cellulose determination was considered to be of the most significance. Because methods described in the literature proved to be unsuitable from the standpoint of reliability when applied to raw and digested sludge, a major effort was made to develop a method of cellulose analysis which would be accurate and reasonably rapid. To do this, a variety of test procedures was investigated until a method capable of effecting over 95 percent recovery in the presence of both raw and digested sludges was attained. This procedure and the recovery tests are described in Appendix H. Tests indicated that more than 98 percent recovery was achieved from raw sludge media when the added cellulose was in the form of small pieces of paper pulp. Cellulose added in the form of finely divided powder could not be recovered to the same extent. In that case losses of 12 to 15 percent were noted, and were attributed to the centrifugation step in the procedure. However. cellulose rarely would be expected to be present to an appreciable degree in the form of minute particles either in normal sludge digesters or in "solid wastes" digesters. No problem was encountered in the recovery of cellulose added in any form to digested sludge.

The high degree of precision of the technique in determining the background cellulose content of digested sludge was indicated by a coefficient of variance (C_v) of 2.91 percent. In the recovery of added cellulose, the C_v was found to be 7.0 percent. For half-strength sewage sludge media, the background C_v was 1.61 percent. Added paper pulp was recovered at a C_v of 3.63 percent. For full-strength sludge the background C_v was 3.53 percent in one test and 2.87 percent in another. In the latter test, added cellulose powder was recovered at a C_v of 2.28 percent.

Experimental Series I: Addition of Green Garbage to Acclimatized Sludge Digesters

The investigation of garbage digestion was pursued along two lines: 1) determination of the maximum proportion of garbage that could be mixed with sewage sludge and successfully digested; and 2) determination of the maximum quantity of garbage in terms of total pounds of organic material (garbage and sludge) that could be digested per cubic foot of digester capacity per day. The first line of investigation was further divided into two aspects — shock loading to digesters not acclimated to large quantities of garbage, and gradual acclimatization of digesters to this material.

In the research reported in the First Annual Report, an experiment was described in which green garbage was fed to unacclimated digesters. It was found that mixtures of up to 76.5 percent garbage and 23.5 percent sludge did not interfere with normal digestion. Richer mixtures than this caused failure within 11 days.

Procedure. Studies described in this report were performed with the use of digester cultures which had survived the first year's experiments and which were gradually acclimated to heavier dosages of garbage. The proportion of garbage in the feed was increased by increments over a two-week period to 80 percent in one digester (Unit 2) and to 83.4 percent garbage in another (Unit 3). These values are equivalent to garbage-sewage solids ratios of 4:1 and 5:1. Loading at these levels proceeded for one month and was then increased to 90 percent garbage fed to Unit 2 and 100 percent garbage to Unit 3. Total volatile solids loading to these digesters and to the control (Unit 1 — fed 100 percent sewage sludge) was 0.077 pounds per cubic foot of digester capacity per day. This schedule was followed for 60 days.

With the completion of the investigation of the relationship between ratio of garbage to sludge on digester performance, the study was directed to the determination of the effect of increasing total loading (quantity). The volatile solids loading was increased incrementally over a three-week period, i.e., until the loading was doubled (0.154 pounds per cubic foot of digester capacity). The proportion of garbage, however, was kept at the previous level. These conditions were maintained for the succeeding two months or two detention periods. During this period, a comparison was made between the effect of mixing and not mixing.

The final step in this stage of the investigation was the making of an abrupt shift from a dosage consisting entirely of garbage to one of raw sewage sludge at the original loading of 0.077 pounds per cubic foot of digester volume per day. This step was carried out to determine the reaction of the digester cultures to a sudden change in the nature of the material fed to it.

Results. The most notable result in the series of experiments was the ability of acclimated digesters to accept high proportions of garbage up to and including 100 percent garbage feed. As is shown in Figure 6, the efficiency of garbage digestion was almost as high as that of sludge digestion; i.e., 14 cubic feet of gas produced per pound of garbage volatile solids destroyed, as compared to 15 cubic feet per pound of sewage sludge volatile solids.

The garbage-fed digesters proved to be capable of handling greater loadings of organic volatile solids than did the sludge-fed digesters. Thus, by the time the loading rate had been doubled, the garbage-fed digesters were continuing to perform satisfactorily, whereas the sludge-fed digesters had failed. At the rate at which the loading was increased, about 20 percent each third day, the control (sludge-fed) failed during the second week when the dosage had reached 140 percent that of the initial loading. At that time, the efficiency of the garbage-fed digesters had declined somewhat, but soon thereafter it was back to the previous level. The digester receiving a dosage consisting of 90 percent garbage had an efficiency about 10 percent higher than that of the unit fed solely on sludge. However, the efficiencies of the two became roughly about equal when both were mixed hourly (the 143rd day of the experiments).

During this stage of the study, photomicrographs (Zeiss 1600 X) were made of the cultures. The morphological types found in the cultures are shown in Figures 7 (sludge-fed digester) and 8 (garbage-fed digester). Judging from the greater variety of morphological types found in the garbage-fed cultures, the diversity of species was greater in it than in the sludge-fed digester. For example, the culture receiving

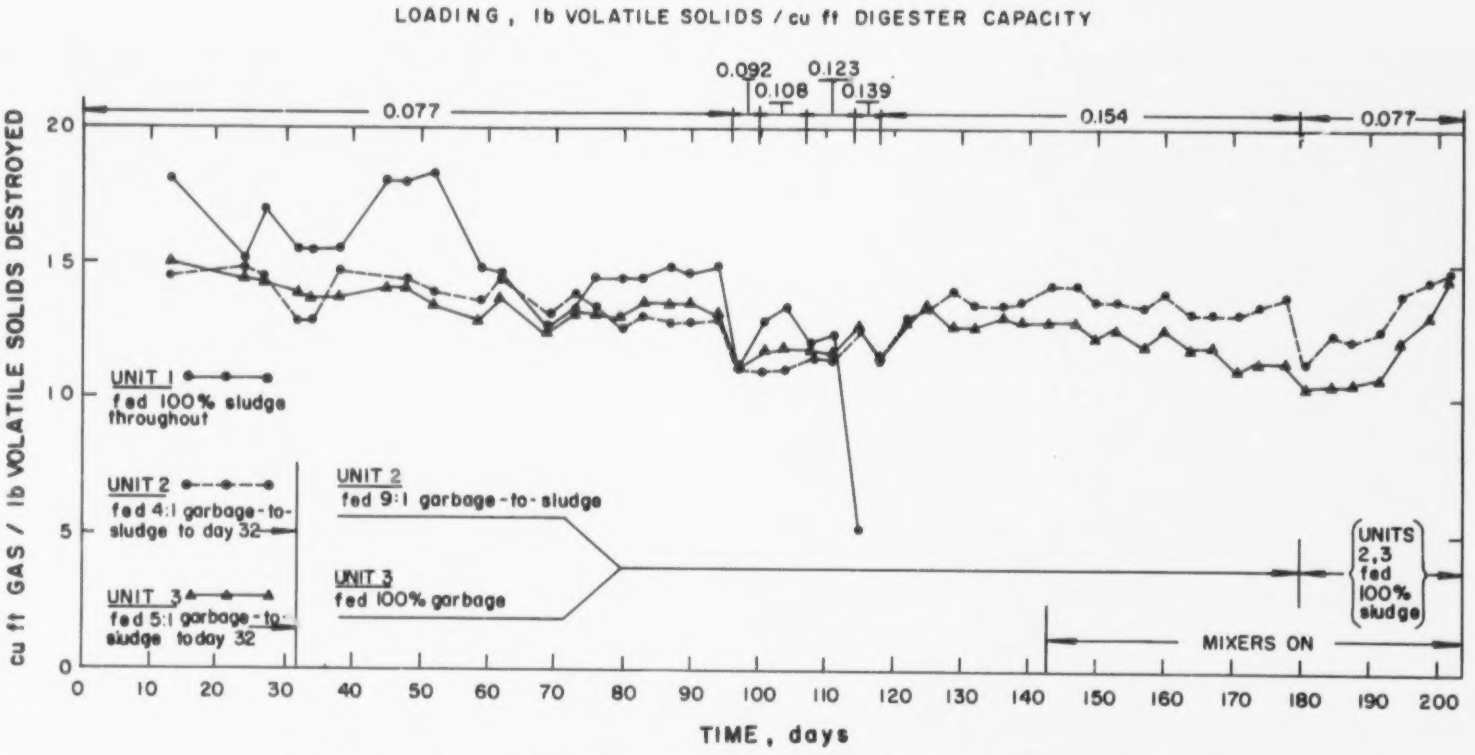

FIGURE 6 EFFICIENCY OF GREEN GARBAGE DIGESTION

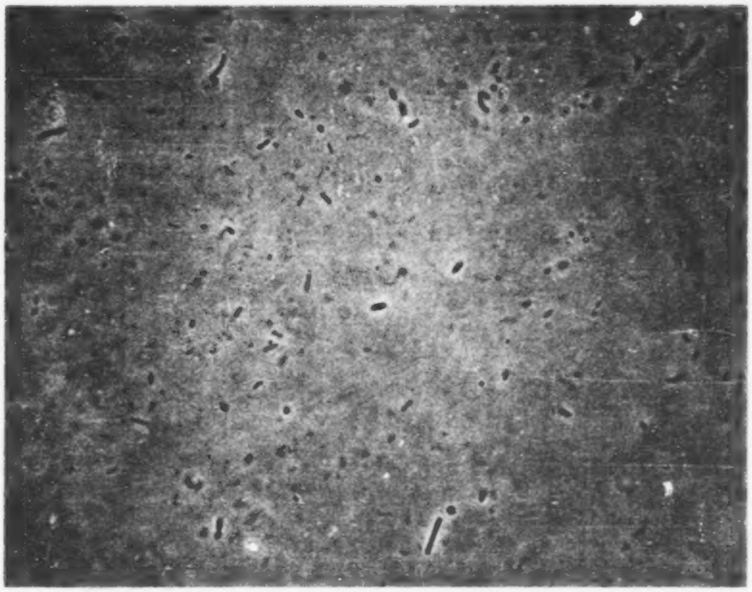

FIGURE 7. MORPHOLOGICAL VARIETY OF MICROORGANISMS FOUND IN THE DIGESTER CULTURE FED ENTIRELY ON SEWAGE SLUDGE

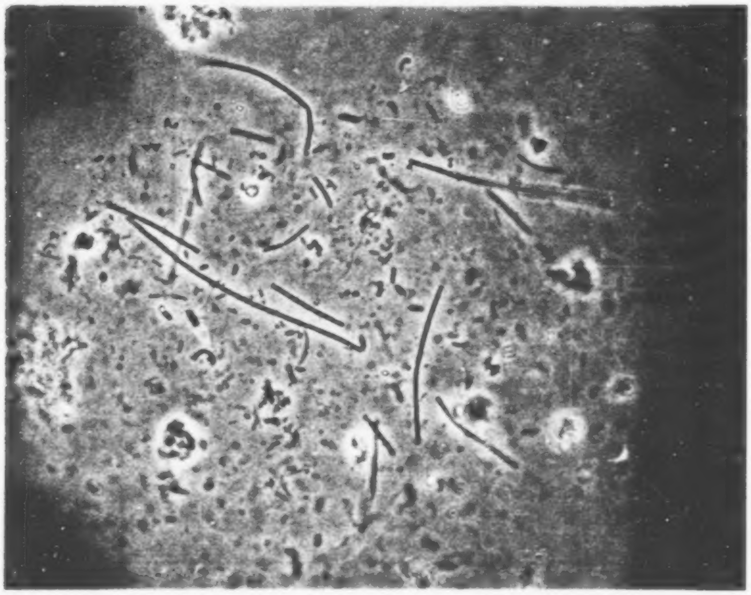

FIGURE 8. MORPHOLOGICAL VARIETY OF MICROORGANISMS IN THE DIGESTER FED ENTIRELY ON GARBAGE

garbage was characterized by an abundance of filamentous spore-formers having long, rod-shaped configurations. None were to be found in the sludge-fed digester. The population observed in each field was related to amount of loading, in that units receiving double the loading to the control (Units 2 and 3) had cell counts almost precisely twice that of the control.

Because of the apparent magnitude of the diversity of species in the garbage-fed digesters, it would be likely that their populations would be sufficiently flexible to cope with sudden changes in nature of and strength of dosage. This proved to be the case, in that the unit fed nothing but garbage (Unit 3) for 150 days showed no unfavorable reaction when the dosage was suddenly switched to 100 percent sludge on the 151st day and thereafter.

According to the curves in Figure 9, in which are indicated total and volatile solids reductions during the course of the experimental run, the rates of destruction of solids were about the same in all three digesters, namely, about 65 percent destruction of volatile solids, and 50 percent of the total solids. These values are comparable to field results for sludge digestion, and are indicative of a quite satisfactory weight and volume reduction of the garbage solids. The rate of reduction in the control dropped only when its failure to function became imminent because of overloading. It also dropped when, toward the end of the run the rate of loading was decreased abruptly. However, instead of showing an immediate and matching decline, the solids reduction was unusually great during the days directly following the drop in dosage rate. This phenomenon undoubtedly was due to the large residual bacterial population remaining from the period of heaving loading. Solids reduction became "normal" after the population shrank to the size supported by the lower dosage.

The ability to maintain a favorable acid-base equilibrium (Figure 10) probably enabled the garbage-fed digesters to adjust without adverse effect to heavy loadings. Initially, their alkalinities were almost double that of the control (5500 mg/ℓ compared to 3000 mg/ℓ), thus indicating a much higher buffering capacity. When the organic loading was increased, volatile acid production rose significantly. This increase was readily buffered in the garbage digesters and was accompanied by a rise in alkalinity to more than 9000 mg/ℓ. The net result was that the increased acid concentration was more than offset, and in fact the pH level increased from 7.5 to 7.8. No such response was observed in the control. Instead, the pH level dropped and the digester failed. It is interesting to note that when the feed rate was returned to its original level (0.077 pounds per cubic foot per day) on the 180th day of the run, the acid-base equilibrium in the garbage-fed digester soon dropped to its original level. These data suggest that feeding large quantities of garbage to anaerobic digesters would establish no irreversible condition. This characteristic would allow for flexible digester loading on a day-to-day basis in terms of both proportion and quantity.

The effect of green garbage loading on the composition of gas produced by the digester is shown in Figure 11. The normalized values indicate that the gas from the control contained 65 percent methane and 35 percent CO_2. The fuel value of the garbage-fed digester gas was somewhat lower; its methane content was about 7 percent lower than that of the gas from the sludge-fed digester, and the CO_2 content was correspondingly higher.

Conclusions. On the basis of the results of the experiments, it may be concluded that acclimated digesters may be fed 100 percent garbage and will perform similarly to normal sludge digesters in terms of solids reduction. Garbage digesters are highly adaptable to varying proportions and quantities of feed, in fact more so than are sludge digesters.

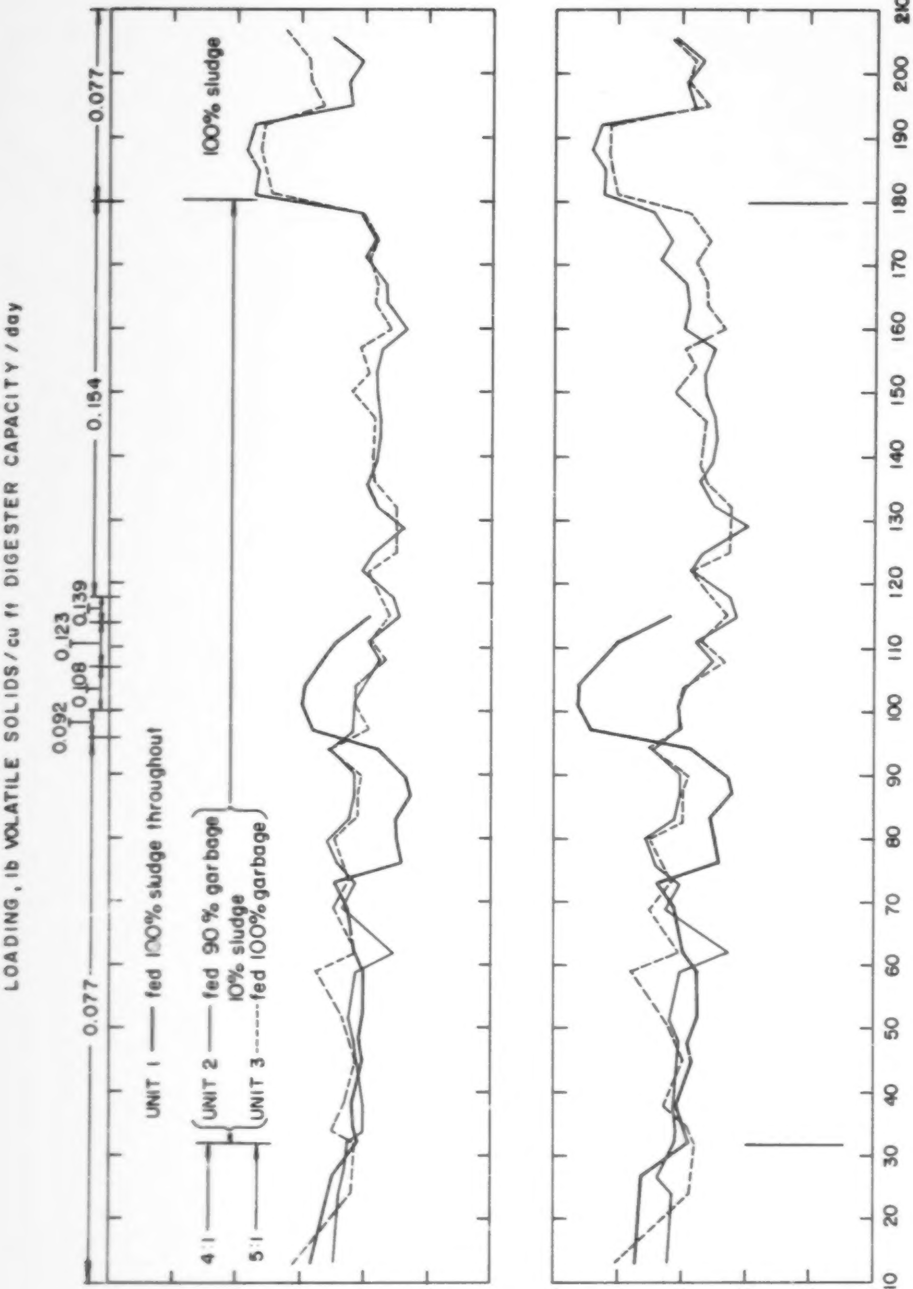

FIGURE 9 . SOLIDS REDUCTION IN GREEN GARBAGE DIGESTION

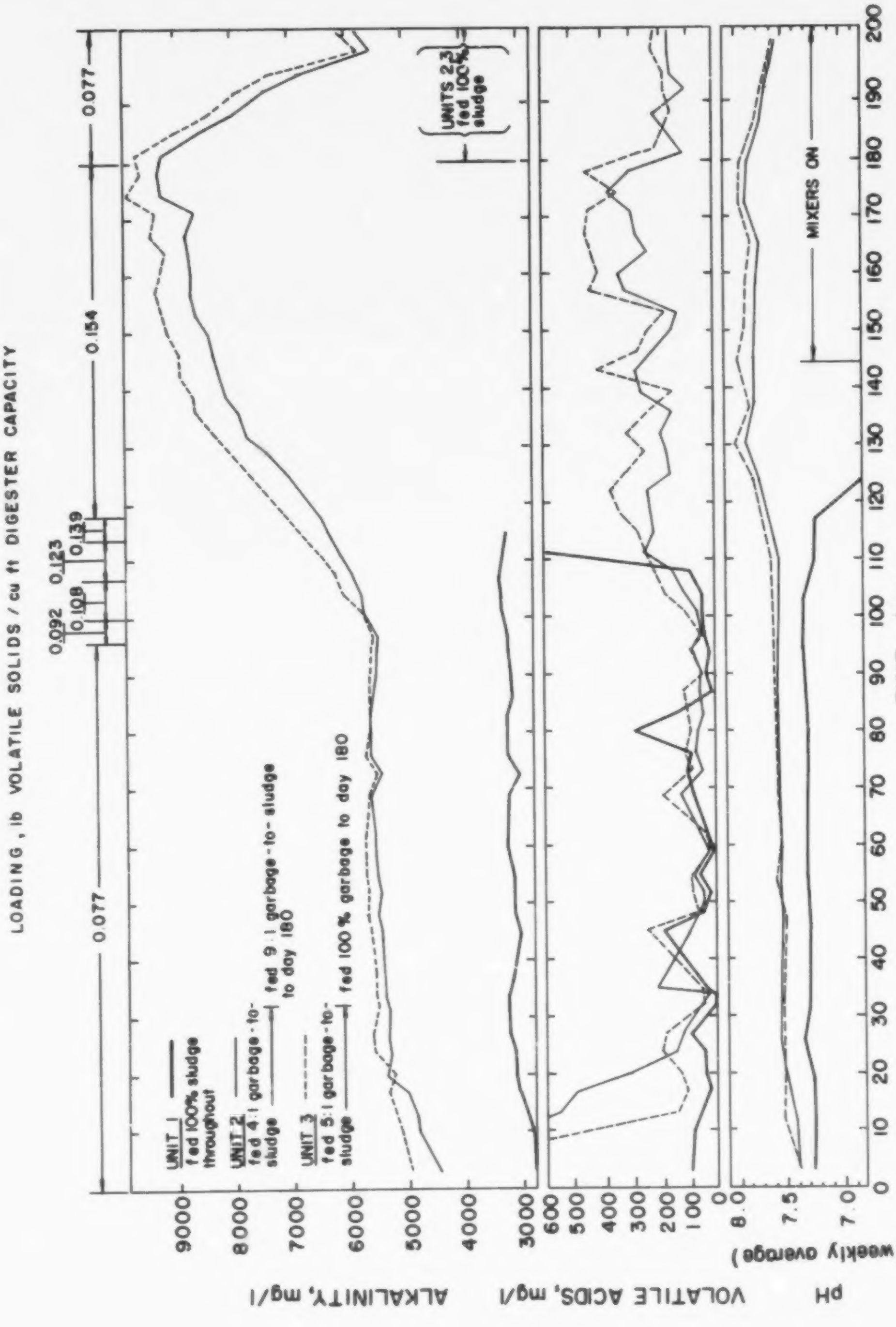

FIGURE 10. EFFECT OF GREEN GARBAGE LOADING ON DIGESTER ACID-BASE EQUILIBRIA

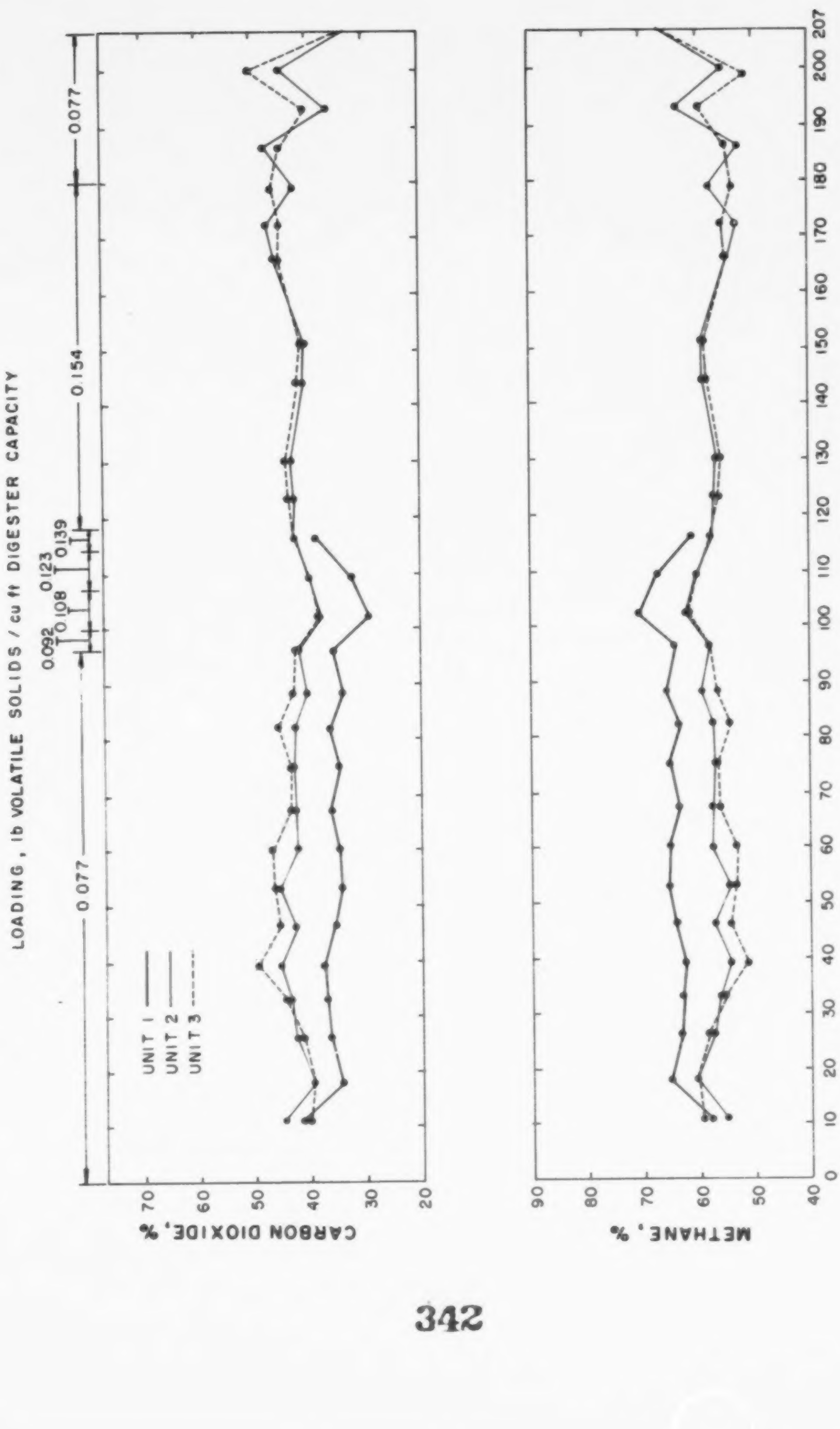

FIGURE 11. EFFECT OF GREEN GARBAGE LOADING ON GAS COMPOSITION

Experimental Series II: Digestion of Paper Pulp

Procedure. The experiments on the digestion of paper pulp were designed to test the digesters over a range of loadings sufficiently wide to establish the maximum proportion which could be efficiently digested in combination with sewage sludge.

Four units were operated initially as "normal" sewage sludge digesters on a theoretical detention period of 30 days. At the end of the 30-day period, feeding with pulp was initiated. The proportion of paper in the dosage was increased incrementally over a three-week period until the following proportions were reached:

Unit A (control) = 100% sewage sludge, 0% paper pulp
Unit B = 50% sewage sludge, 50% paper pulp
Unit C = 40% sewage sludge, 60% paper pulp
Unit D = 31.8% sewage sludge, 68.2% paper pulp

This feeding program was followed for the remainder of the experiment — a period of four months.

Results. Since, as previously noted, the paper pulp was essentially pure cellulose, the best indicators of extent of digestion were those results pertaining to destruction of cellulose. The contribution of sewage sludge to the total cellulose input was determined by taking weekly measurements of the cellulose content of the sludge feed. As shown in Table 29, the average cellulose content of the feed was 35.6 percent of the dry weight total solids. Despite the need for using several batches of sludge during the course of the experiment, the cellulose content remained remarkably constant. The respective amounts of cellulose contributed by the sludge and by the paper pulp in the daily feed are given in Table 30.

The extent of the destruction or degradation of the incoming cellulose and the concentration of the residual cellulose in the digester sludge (g/100 mℓ) are indicated by the data in Table 31. The results demonstrate conclusively that the test digesters could use paper pulp as a substrate and digest it without any observable adverse effects. In digesters B (equal parts sludge and paper) and C (40 parts sludge and 60 parts cellulose), destruction averaged more than 90 percent. The residual cellulose per total solids in the two units was only 17 to 18 percent, an amount which was only very slightly higher than the 15 percent residual in the control. Judging from these facts, the addition of sizable quantities of paper pulp would have but little residual effect on the characteristics of anaerobic digester sludge. Unit D (32 parts sludge to 68 parts pulp) ultimately failed for reasons which will be discussed later. However, prior to its failure, it was quite efficient in breaking down the incoming cellulose. The high rate of cellulose destruction (80 percent) in Unit A, the control, indicates that normal sludge digesters are also highly efficient in degrading cellulose.

The extent of cellulose and volatile solids reduction, as well as amount of gas produced per pound of volatile solids destroyed, are plotted in Figure 12. According to that figure, volatile solids reduction in the digesters fed paper was more extensive than that in the control, namely, an average of about 75 percent in the former and 65 percent in the latter. However, if efficiency were to be measured in terms of gas production, the control would be superior. On the basis of gas production per unit of volatile solids destroyed, gas production dropped as the proportion of paper was increased. According to Table 32, the average values were 15.1 cubic feet for Unit A (100 percent sludge), 12.9 cubic feet for Unit B (50 percent sludge — 50 percent paper), 12.1 cubic feet for Unit C (40 percent sludge — 60 percent paper), and 11.1 cubic feet for Unit D (32 percent sludge — 68 percent paper).

TABLE 29

CELLULOSE CONTENT OF PRIMARY SLUDGE FEED DURING PAPER PULP DIGESTION EXPERIMENTAL RUNS

Day	Influent Primary Sludge	
	Cellulose g/100 mℓ	Cellulose/Total Solids %
50	1.716	36.5
57	1.856	39.5
64	1.964	41.9
71	2.032	42.2
78	1.680	33.1
85	1.832	40.1
92	1.212	23.2
99	1.788	39.2
106	1.464	30.5
113	1.632	35.4
120	1.916	32.0
Avg.	1.736	35.8

TABLE 30

DAILY INPUT OF CELLULOSE TO DIGESTERS

To Unit	Cellulose Added, g		
	From Paper Pulp	From Sludge Feed	Total
A	0	1.736	1.736
B	1.735	0.868	2.603
C	2.082	0.690	2.772
D	2.369	0.552	2.921

TABLE 31

CELLULOSE DESTRUCTION IN THE DIGESTERS
(Paper Pulp)

Day	Digester Sludge											
	Unit A: 100% Sludge			B. 50% Sludge—50% Paper			C. 40% Sludge—60% Paper			D. 32% Sludge—68% Paper		
	Residual Cellulose g/100 mℓ	Destruction %	Cellulose Total Solids %	Residual Cellulose g/100 mℓ	Destruction %	Cellulose Total Solids %	Residual Cellulose g/100 mℓ	Destruction %	Cellulose Total Solids %	Residual Cellulose g/100 mℓ	Destruction %	Cellulose Total Solids %
50	0.510	70.6	22.6	0.263	89.9	17.8	0.312	88.7	22.2	0.385	86.8	28.4
57	0.344	80.2	14.9	0.276	89.4	17.6	0.227	91.8	16.2	0.375	87.2	25.2
64	0.338	80.5	14.1	0.251	90.4	14.9	0.160	94.2	10.6	0.424	85.5	24.4
71	0.279	83.9	14.3	0.217	91.7	14.5	0.193	93.0	14.7	0.602	79.4	42.4
78	0.307	82.3	15.2	0.242	90.7	15.7	0.262	90.5	19.0	-	-	-
85	0.300	82.7	14.9	0.244	90.6	16.0	0.264	90.5	20.8	-	-	-
92	0.281	83.8	13.9	0.307	88.2	23.4	0.244	91.2	20.5			
99	0.290	83.3	13.7	0.238	90.9	17.5	0.253	90.9	19.1			
106	0.292	83.2	13.0	0.218	91.6	15.5	0.219	92.1	17.8			
113	0.331	80.9	15.0	0.277	89.4	17.6	0.253	90.9	19.5			
120	0.343	80.2	15.4	0.261	90.0	18.1	0.248	91.1	18.7			
Avg.	0.329	81.1	15.2	0.254	90.3	17.1	0.264	91.4	18.1	0.447	84.7	30.1

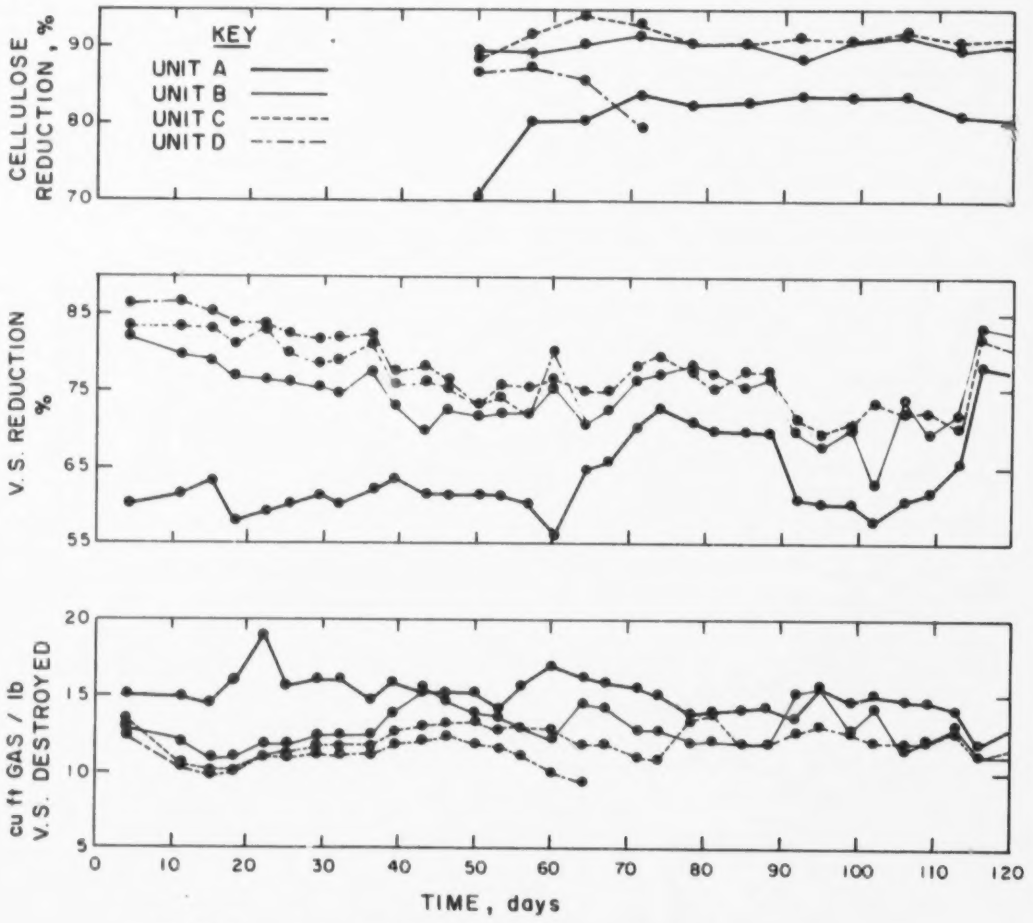

FIGURE 12. EFFICIENCY OF PAPER DIGESTION

TABLE 32

EFFICIENCY OF PAPER PULP DIGESTION

Day	cu ft Gas Produced/lb Volatile Solids Destroyed/day			
	Unit A 100% Sludge	Unit B 50% Sludge–50% Paper	Unit C 40% Sludge–60% Paper	Unit D 32% Sludge–68% Paper
4	15.1	13.1	13.5	12.5
11	15.1	12.0	10.5	10.4
15	14.6	10.8	10.0	9.9
18	15.8	11.0	10.2	10.1
22	19.0	11.9	10.8	11.0
25	15.6	11.8	11.3	11.0
29	16.0	12.4	11.7	11.2
32	16.2	12.5	11.7	11.2
36	14.8	12.4	11.7	11.1
39	15.8	13.8	12.6	11.8
43	15.2	15.5	13.1	12.1
46	15.2	14.7	13.2	12.4
50	15.3	14.0	13.3	11.9
53	14.2	13.9	12.9	11.7
57	15.8	12.8	12.9	11.2
60	17.0	12.1	12.9	10.0
64	16.3	14.6	11.9	9.5
67	16.0	14.4	12.0	
71	15.7	12.9	11.1	
74	15.2	12.8	11.0	
78	13.9	12.1	13.4	
81	14.1	12.2	13.9	
85	14.1	11.8	11.8	
88	14.2	11.6	11.8	
92	13.6	15.3	12.6	
95	15.6	15.7	13.0	
99	14.6	12.8	12.5	
102	15.1	14.3	12.0	
106	14.9	11.5	11.9	
109	14.7	12.2	11.9	
113	14.2	13.0	12.7	
116	11.9	12.8	11.0	
120	12.6	11.3	11.4	
Avg.	15.1	12.9	12.1	11.1

Data concerned with reduction in total solids are presented in Table 33. According to the data, a weight reduction of almost 70 percent occurred in the digesters which received paper. Since the residual solids were shown by the cellulose determinations to have been derived almost exclusively from the sludge portion of the feed, the digesters must have been very effective in accomplishing the destruction of the paper portion of the feed.

The relation between feed composition (i.e., sludge-to-paper ratio) is shown by the slopes of the curves in Figure 13, in which is plotted change in alkalinity that occurred during the course of the experiment. The alkalinity in Unit D (32 parts sludge to 68 parts paper) dropped very rapidly and when the level reached 800 mg/ℓ, the culture failed. Although the alkalinity in Unit C (40 parts sludge to 60 parts paper) also dropped, it leveled off at 850 mg/ℓ and continued at that level without any obvious inhibitory effect on the digester. Judging from these results, the ratio of 40 parts sludge to 60 parts paper approximates the critical ratio. However, since the biological effects of this proportion of paper to sludge are due to the C:N ratio (45:1) resulting from such a mixture rather than to anything intrinsic to the ingredients themselves; any increase in the nitrogen content of the sludge or through some additive could result in a higher permissible proportion of paper to sludge.

The critical pH level associated with the safe operating level of alkalinity of 800 mg/ℓ (as carbonate) apparently was 6.5, inasmuch as Unit C functioned successfully during the latter half of the experimental period at a pH of 6.6 to 6.7.

The effect of paper pulp loading on gas composition is shown by relative positions of the curves in Figure 14. As was observed in the experiments on garbage loading, a shift took place from methane to CO_2 production. The normalized values show that the gas from the digesters fed paper averaged 65 percent methane, approximately 5 percent less than that from the control. No significant differences were noted between the gas compositions of the three test units.

Conclusions. In terms of weight and volume reduction, the digestion of paper pulp proved to be an effective means of disposing of that material, inasmuch as the degradation of its cellulose content was as much as 90 percent. Loading with respect to paper should not become critical until the percentage of paper exceeds 60 percent, i.e., until the resulting C:N ratio exceeds 45:1. Failure occurred in the experiments when the paper-to-sludge ratio was 68 to 32, at which stage the C:N ratio of the feed was 52:1.

Experimental Series III: Digestion of Combined Solid Wastes

The effectiveness of combining different types of wastes materials and digesting them in special "solid wastes digesters" was evaluated in experiments involving the use of chicken manure and paper pulp. The carbon-to-nitrogen ratio was investigated over a broad range to determine the maximum quantity of paper that could be disposed of with a limited amount of chicken manure.

Procedure. Three digesters were used in these experiments. Three liters of digesting sewage sludge, obtained from a nearby treatment plant, were placed in each of the units to serve as starting cultures. One digester, Unit 6, was made to serve as a control. It received 100 mℓ of sewage sludge daily. The other two digesters were gradually acclimated to receiving a feed having the proportions of chicken manure and paper pulp suited to the needs of the experiment. The period of acclimatization lasted 16 days. During the initial phase of the experiment (118 days), the proportions were as follows:

TABLE 33

PERCENT TOTAL SOLIDS REDUCTION IN PAPER PULP DIGESTION

Day	Unit A 100% Sludge	Unit B 50% Sludge—50% Paper	Unit C 40% Sludge—60% Paper	Unit D 32% Sludge—68% Paper
4	47.5	72.0	75.2	79.2
11	48.4	70.0	75.2	79.7
15	49.2	69.1	75.0	78.4
18	44.1	66.8	71.9	76.3
22	37.3	66.2	74.3	75.0
25	45.7	66.4	71.0	74.7
29	46.8	65.4	69.5	74.3
32	46.0	64.7	70.0	74.3
36	47.2	67.3	71.9	74.7
39	43.8	62.4	66.2	69.6
43	46.2	59.4	66.9	70.1
46	46.2	62.4	66.1	68.7
50	45.8	61.5	63.7	65.5
53	46.0	61.7	65.9	66.7
57	45.0	61.7	66.2	64.5
60	41.8	65.4	65.9	72.0
64	48.2	61.3	65.7	64.3
67	49.3	61.9	65.2	
71	55.8	67.5	70.6	
74	57.6	68.2	71.3	
78	56.3	69.2	70.0	
81	55.4	68.2	67.6	
85	55.4	66.3	69.8	
88	55.0	67.5	69.8	
92	45.5	59.2	62.2	
95	44.8	57.6	60.5	
99	44.8	59.6	61.6	
102	43.2	53.5	64.3	
106	45.0	62.8	63.1	
109	45.6	59.4	63.1	
113	48.5	61.3	62.0	
116	64.5	75.1	75.1	
120	64.1	74.6	73.9	
Avg.	48.7	64.7	68.2	72.2

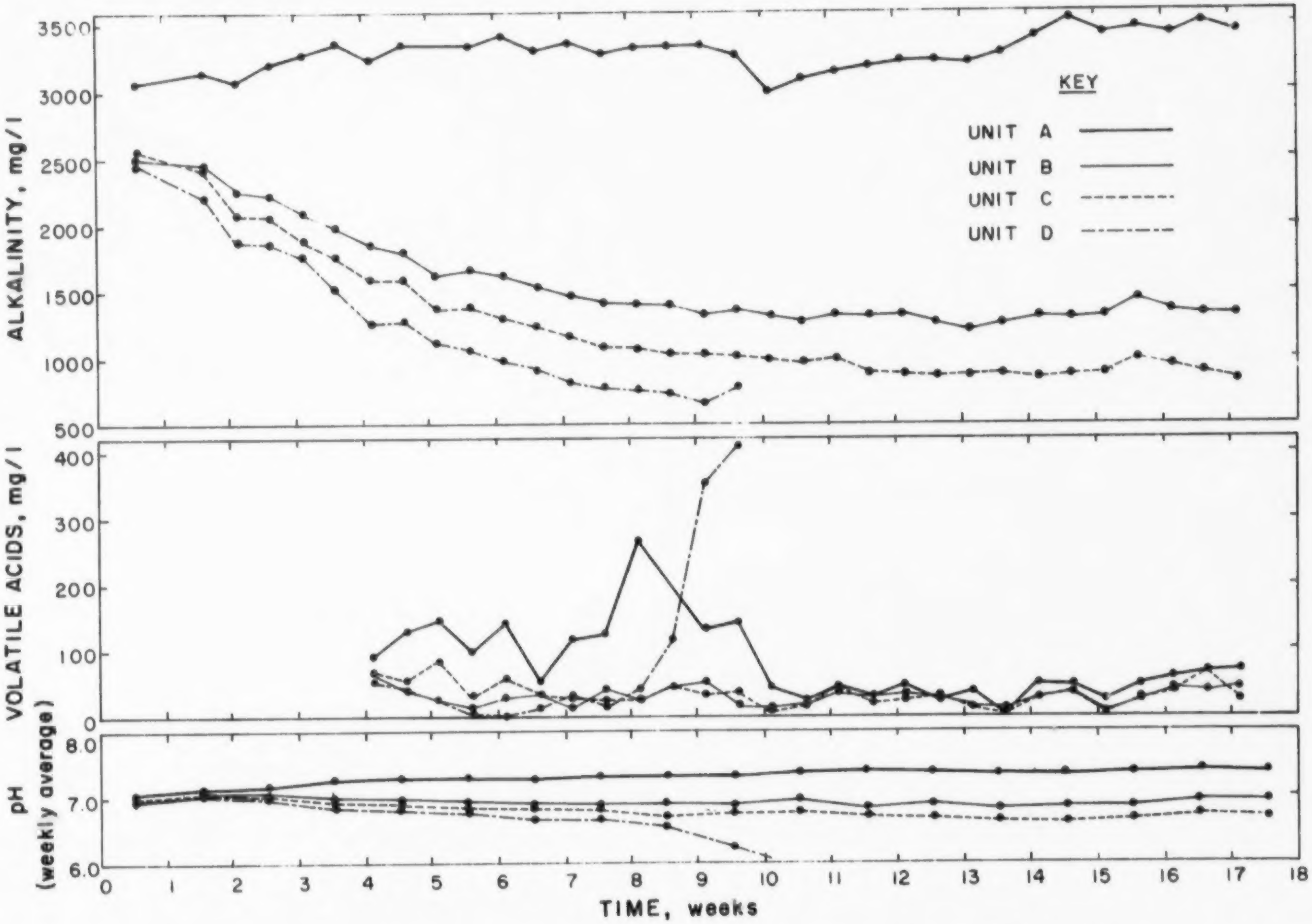

FIGURE 13 EFFECT OF PAPER PULP LOADING ON DIGESTER ACID-BASE EQUILIBRIA

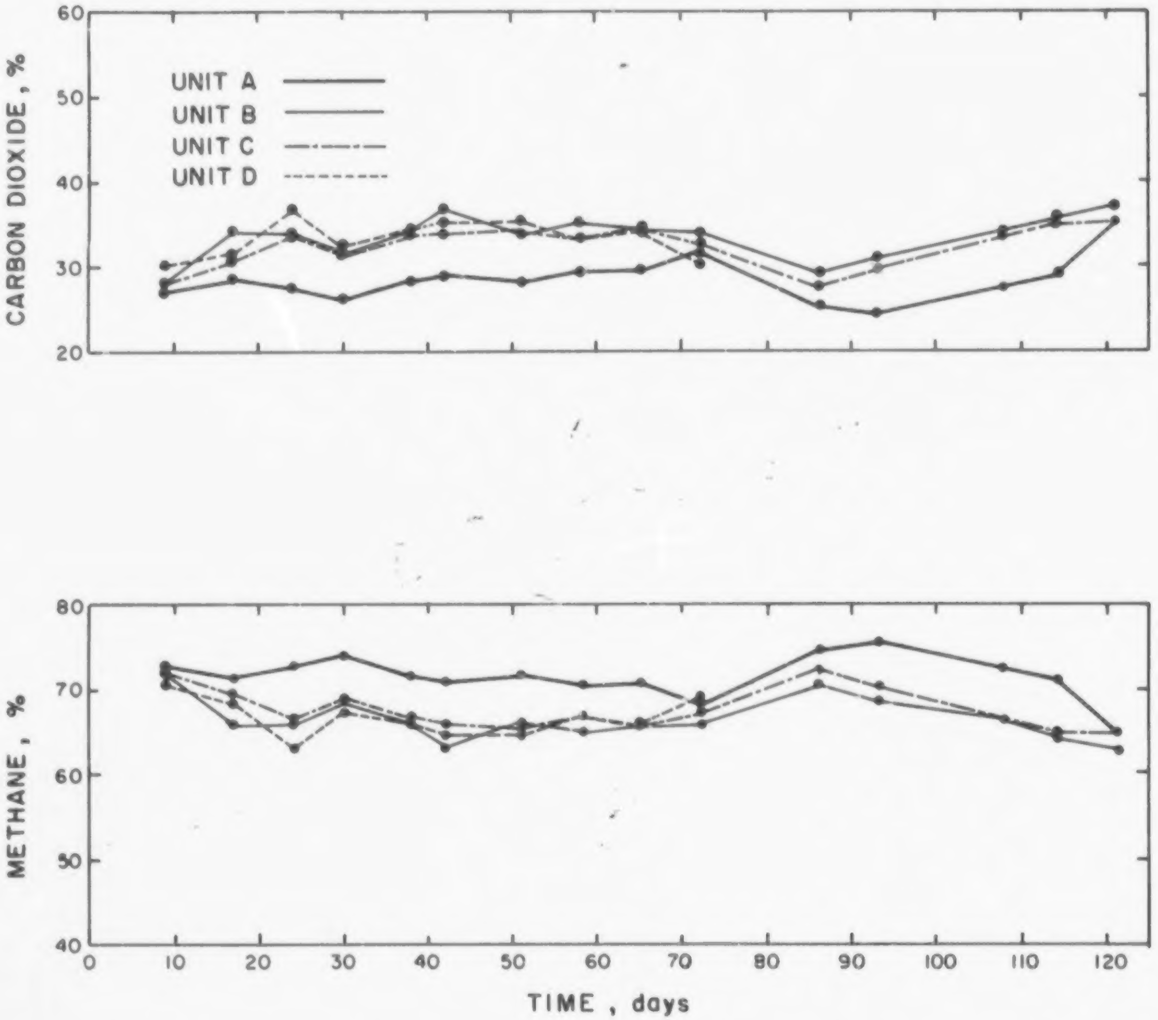

FIGURE 14 . EFFECT OF PAPER PULP LOADING ON GAS COMPOSITION

Unit	Chicken Manure %	Paper Pulp %	C:N
7	50	50	30:1
12	30.7	69.3	60:1

During the succeeding 42 days the proportions were changed to:

7	28.8	71.2	65:1
12	27.2	72.8	70:1

In the final phase (44 days) Unit 12 was fed:

12	25.7	74.3	75:1

Volatile solids loading remained at 0.077 pound per cubic foot digester capacity per day throughout the course of the experiment.

Results. The efficiency and performance of all digesters during the initial phase of the experiment was quite satisfactory. This is indicated in Figure 15, in which gas production is plotted in terms of volume per liter of culture and volume per unit weight of volatile solids destroyed. Generally, volume of gas production in the control was 10 to 20 percent greater than that in the "solid wastes" digesters, but the volume per pound of volatile matter destroyed was about the same. These results indicate that although the volatile solids were destroyed at a slower rate than those in the control, on a "per pound" basis gas production was comparable to that in the control.

A similar trend was noted during the second phase (days 117 to 167) of the run, during which time the carbon-to-nitrogen ratios were increased in Unit 7 to 65:1, and in Unit 12, to 70:1. These results are surprising in view of the fact that conventional sludge digesters generally fail at C:N ratios higher than 50:1. The reason for absence of inhibition in the "solid wastes" digesters may have been the resistance of the manure to decomposition, and the consequently gradual release of carbon. Thus, carbon may have been only slowly available for bacterial metabolism, and as a result the effectual C:N ratio may have remained at a satisfactory level, even though the absolute level was higher than that normally permissible.

In the final phase of the run, in which the C:N in Unit 12 was increased to 75:1, volume of gas production and volume per pound of volatile matter destroyed were adversely affected. That the culture was not functioning properly at this loading is apparent from Figure 15, but the magnitude of the difficulty is better realized from the change in acid-base relationships involved. As shown in Figure 16, the volatile acids production soared to more than 2000 mg/ℓ and the pH dropped to 6.0. This condition, of course, was severe enough to cause digester failure.

Although most of the parameters of digester performance would indicate that Unit 12 was functioning properly when the C:N of its feed was 70:1, it is highly uncertain that the condition would have persisted under a prolonged dosage at this C:N level. The alkalinity results cast a measure of doubt on the possibility of the continued successful functioning of the experimental digesters operated at both 65:1 and 70:1, since their alkalinity concentrations continued to decrease throughout the 50 days of the second experimental phase. If the decline were to have continued at this same rate in the two digesters, the critical level of 750 to 800 mg/ℓ alkalinity would have been reached after an additional three to four months of operation. However, it is more than likely that the two units would have stabilized, as occurred in the experiments on paper digestion. The alkalinity of the two units was considerably above the lowest permissible level at the time the feeding program was changed.

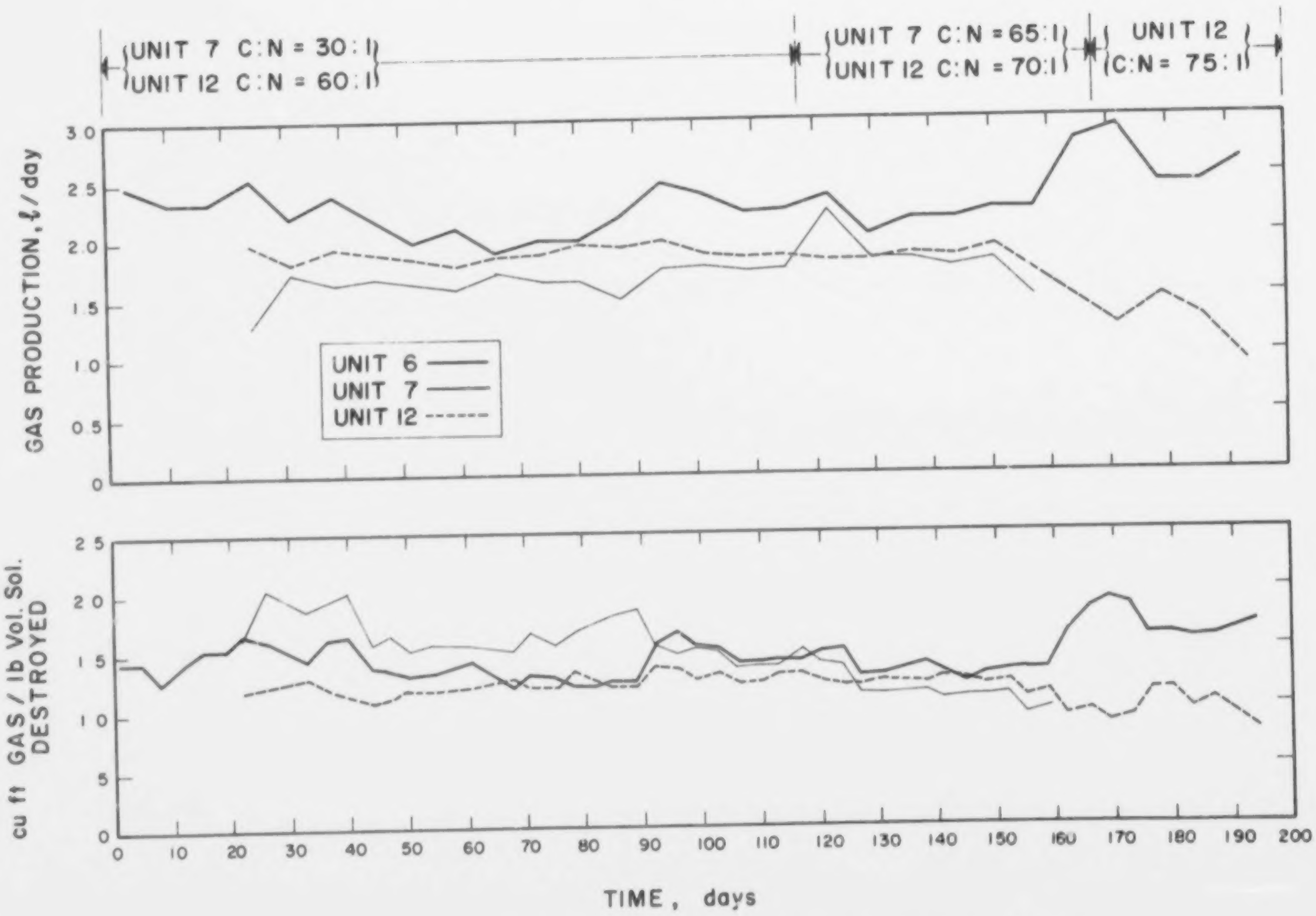

FIGURE 15. EFFICIENCY OF COMBINED WASTES DIGESTION

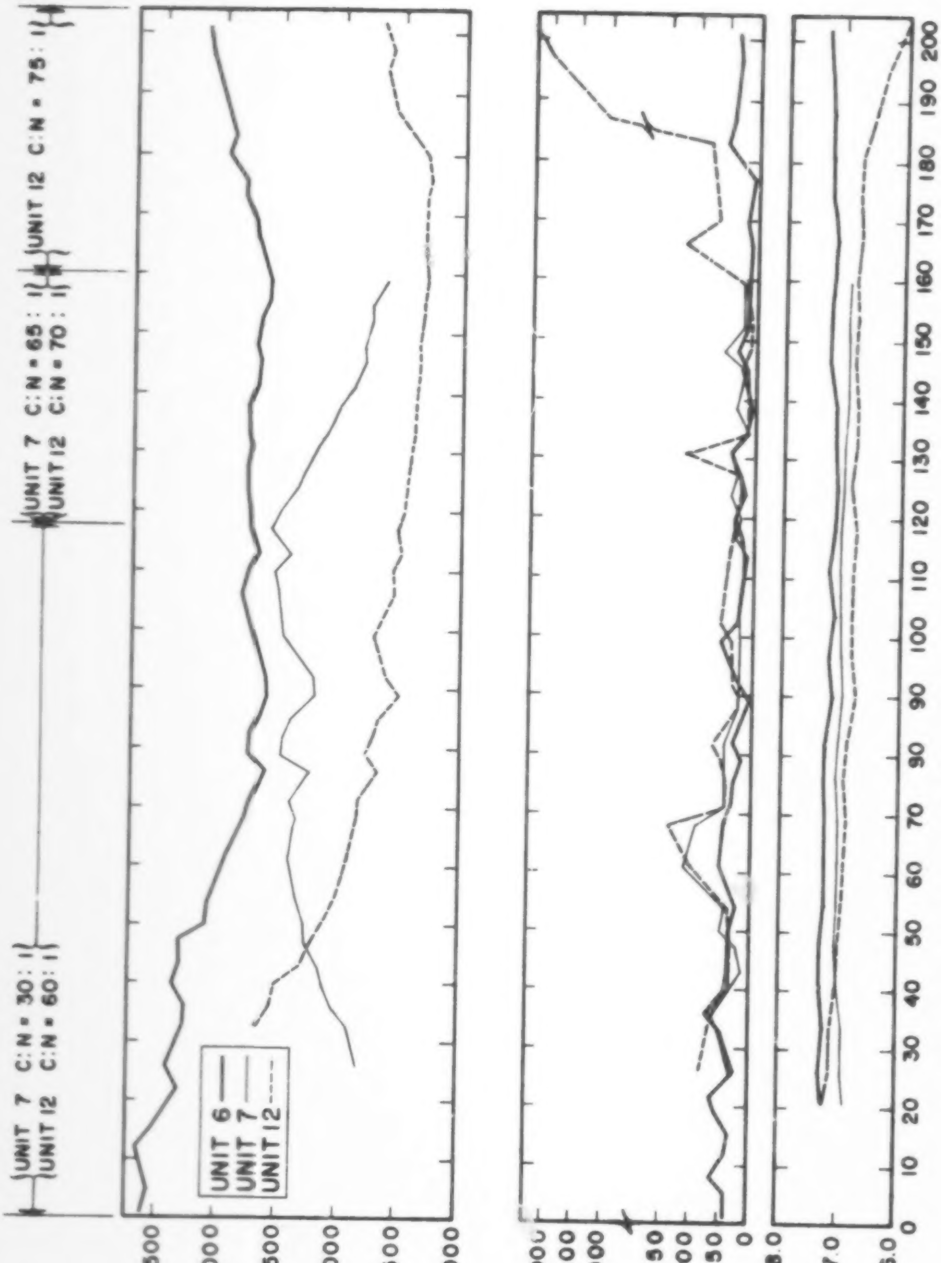

FIGURE 16. EFFECT OF COMBINED WASTES ON DIGESTER ACID-BASE EQUILBRIA

Total and volatile solids reduction was less in the digesters fed chicken manure than in the control, as is shown by the curves in Figure 17. This was particularly true when Unit 7 was receiving a large proportion of manure during the initial phase, at which time the destruction in the unit was from 10 to 15 percent less than that in the control. The lower degree of destruction was a function of the large amount of inorganic material (mostly sand) present in the manure. (The fixed solids content of the manure was 44 percent.) That the apparently low rate of destruction was due to the high percentage of fixed solids in the manure was shown by increase in destruction of volatile matter in the second phase of the experimental run. In this phase, the proportion of manure was reduced, while that of paper pulp, an almost completely organic material, was increased. In this phase, reduction was very nearly the same as in the control, viz., about 50 percent of the total solids and 65 percent of the volatile solids.

The extent of cellulose reduction approximated that which took place in the previous experiment, in which sludge had been the nitrogen source. As indicated by the curves in Figure 17, approximately 90 percent of input cellulose was degraded. From 82 to 86 percent of the cellulose fed to the control was destroyed.

In Table 34 are listed average values for cellulose reduction during each phase of the experiment, for residual cellulose in terms of concentration, and as a percent of both total and volatile solids in the digested sludge. The total input of cellulose per day indicated in the table is the sum of portions contributed by the chicken manure and the paper pulp. Since on a dry-weight basis the chicken manure was 16.8 percent cellulose, cellulose coming by way of the manure accounted for 9.3 to 23.0 percent of the total cellulose entering the digesters, depending upon the proportion of manure to paper.

Extent of cellulose destruction increased with increase in the ratio of paper pulp to manure in Phase 2 of the run. Thus, the destruction in Unit 7 was 2.3 percent higher than in Phase 1; and in Unit 12, 1.4 percent higher than in Phase 1. The difference in the amount of increase between the two units was consistent with the amount of chicken manure replaced by paper pulp in the Phase 2 feed to the two digesters. In Phase 1, the ratio of pulp to manure was 50:50 in Unit 7, and 31:69 in Unit 12; in Phase 2, the ratios were 29:71 and 27:73, respectively. The results indicate that the cellulose supplied in the form of paper pulp was more readily degraded than that associated with chicken manure.

Judging from the results, a mixture, 70 percent of which is paper pulp and 30 percent is chicken manure, could be digested quite readily and with a reasonably low percentage of residual solids. In the experiments, only 25 percent of the residual solids was in the form of cellulose, a percentage similar to that in digested sludge. On the basis of observations made in the experiments on paper-sewage-sludge mixtures, it may be assumed that most of this residual cellulose was from the chicken manure. In terms of total solids, the cellulose residual constituted only 15 percent of the total.

Records of the CO_2 and CH_4 in the gas produced by the digesters are shown in Figure 18. In common with results obtained in the previous experiments, the digestion of solid wastes materials was characterized by the production of a gas lower in CH_4 content than is generally the case in the digestion of sewage sludge. In the present experiment, the concentration of CH_4 in the gas from the solid wastes digesters was about 7 percent less than that in the control. That the difference was not due solely to differences in C:N ratios is shown by the fact that the CH_4:CO_2 ratio remained about the same at all of the ratios tried in the experiment.

Conclusions. The major conclusion to be drawn from the results of the experiment is that a solid wastes digester can be readily maintained with the use of chicken manure as the nitrogen source. According to the results, paper pulp may be applied in quantities sufficient to bring the C:N ratio of the feed up to 70:1. At this C:N ratio, the proportion of paper pulp would be about 73 percent. Under these conditions, reduction in cellulose content should be on the order of 90 percent.

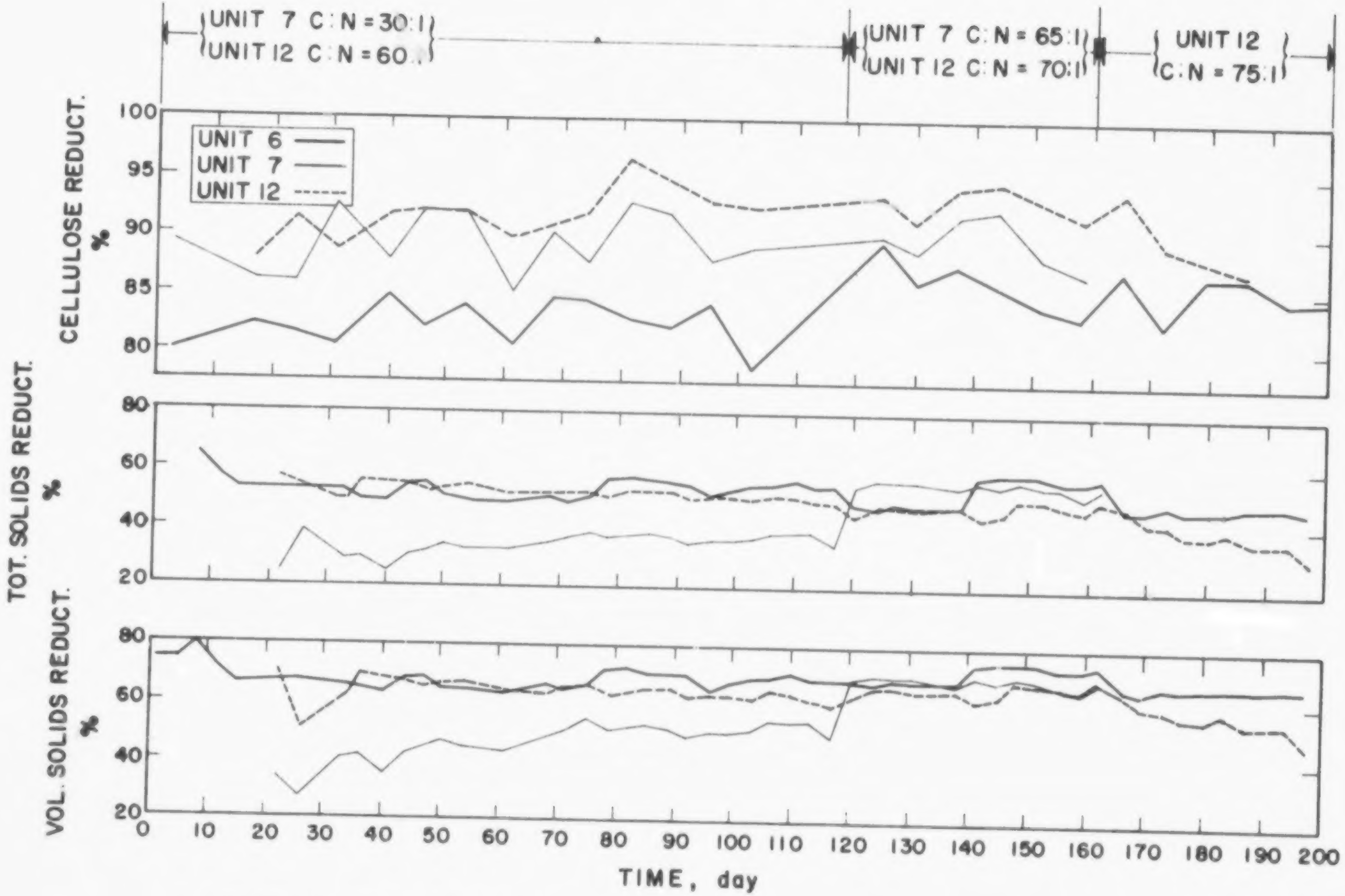

FIGURE 17. SOLIDS REDUCTION IN COMBINED WASTES DIGESTION

TABLE 34

EFFICIENCY OF CELLULOSE REDUCTION IN COMBINED WASTES DIGESTION

Day	Unit 6				Unit 7				Unit 12			
	Digester Residual Cellulose				Digester Residual Cellulose				Digester Residual Cellulose			
	g/100 ml	Total Solids %	Volatile Solids %	Removal %	g/100 ml	Total Solids %	Volatile Solids %	Removal %	g/100 ml	Total Solids %	Volatile Solids %	Removal %
	Input/day: 1.736 g cellulose				Input/day: 2.408 g cellulose				Input/day: 2.910 g cellulose			
3	0.348	15.5	28.7	80.0	0.258	15.6	21.7	89.3	-	-	-	-
17	0.307	14.3	25.6	82.3	0.333	23.0	35.5	86.2	0.348	16.7	30.2	88.0
24	0.317	14.2	26.0	81.7	0.335	16.1	24.9	86.1	0.251	14.3	21.4	91.4
31	0.337	14.7	26.3	80.6	0.178	11.8	19.6	92.6	0.325	18.5	32.5	88.8
40	0.263	11.7	20.9	84.9	0.292	15.3	24.4	87.9	0.239	13.7	19.0	91.8
46	0.310	14.6	26.7	82.1	0.193	13.8	23.5	92.0	0.223	16.0	27.3	92.3
53	0.277	13.7	25.4	84.0	0.192	17.9	32.0	92.0	0.229	20.7	36.3	92.1
61	0.335	14.4	26.6	80.7	0.362	17.4	29.6	85.0	0.293	20.2	33.9	89.9
68	0.266	14.9	28.7	84.7	0.236	19.3	34.3	90.2	0.266	26.4	44.3	90.9
74	0.270	14.1	27.3	84.4	0.296	23.8	44.4	87.7	0.233	23.4	40.2	92.0
81	0.297	14.8	28.4	82.9	0.171	10.3	18.9	92.9	0.103	9.5	16.1	96.5
88	0.309	16.6	30.8	82.2	0.196	14.0	25.3	91.9	0.148	15.2	25.8	94.9
95	0.273	13.2	22.8	84.3	0.289	15.8	28.4	88.0	0.202	13.9	23.3	93.1
102	0.368	18.8	33.5	78.8	0.265	15.7	30.8	89.0	0.214	16.3	26.8	92.6
Avg.	0.306	14.7	26.7	82.4	0.257	16.3	27.5	89.3	0.236	16.9	27.2	91.9
	Input/day: 1.736 g cellulose				Input/day: 2.959 g cellulose				Input/day: 3.000 g cellulose			
124	0.181	9.5	16.9	89.6	0.241	10.0	18.3	91.9	0.185	10.9	18.0	93.8
130	0.242	13.7	25.0	86.0	0.273	15.9	28.9	90.8	0.252	15.2	24.6	91.6
137	0.218	11.8	21.2	87.5	0.200	11.7	20.6	93.2	0.167	12.2	19.9	94.4
141	0.216	14.7	26.4	85.8	0.186	22.8	40.5	93.7	0.154	16.9	26.8	94.9
151	0.283	16.3	28.5	83.7	0.279	14.6	26.0	90.6	0.199	12.9	21.4	93.4
158	0.293	18.2	31.1	83.1	0.313	16.6	27.9	89.4	0.245	20.0	32.4	91.8
Avg.	0.239	13.9	24.7	86.0	0.249	14.3	25.3	91.6	0.200	14.3	23.5	93.3
	Input/day: 1.736 g cellulose								Input/day: 3.044 g cellulose			
165	0.222	13.2	22.5	87.2					0.187	19.9	31.7	93.8
172	0.301	17.8	30.5	82.6					0.324	27.4	41.3	89.4
179	0.227	17.7	21.9	86.9					0.355	25.2	37.0	88.3
186	0.229	13.3	23.0	86.8					0.388	27.8	40.4	87.2
193	0.265	14.6	25.2	84.7					0.482	30.7	44.5	84.2
200	0.263	13.9	24.1	84.8					0.537	28.5	37.9	82.4
Avg.	0.251	14.2	24.5	85.5					0.379	27.2	39.2	87.5

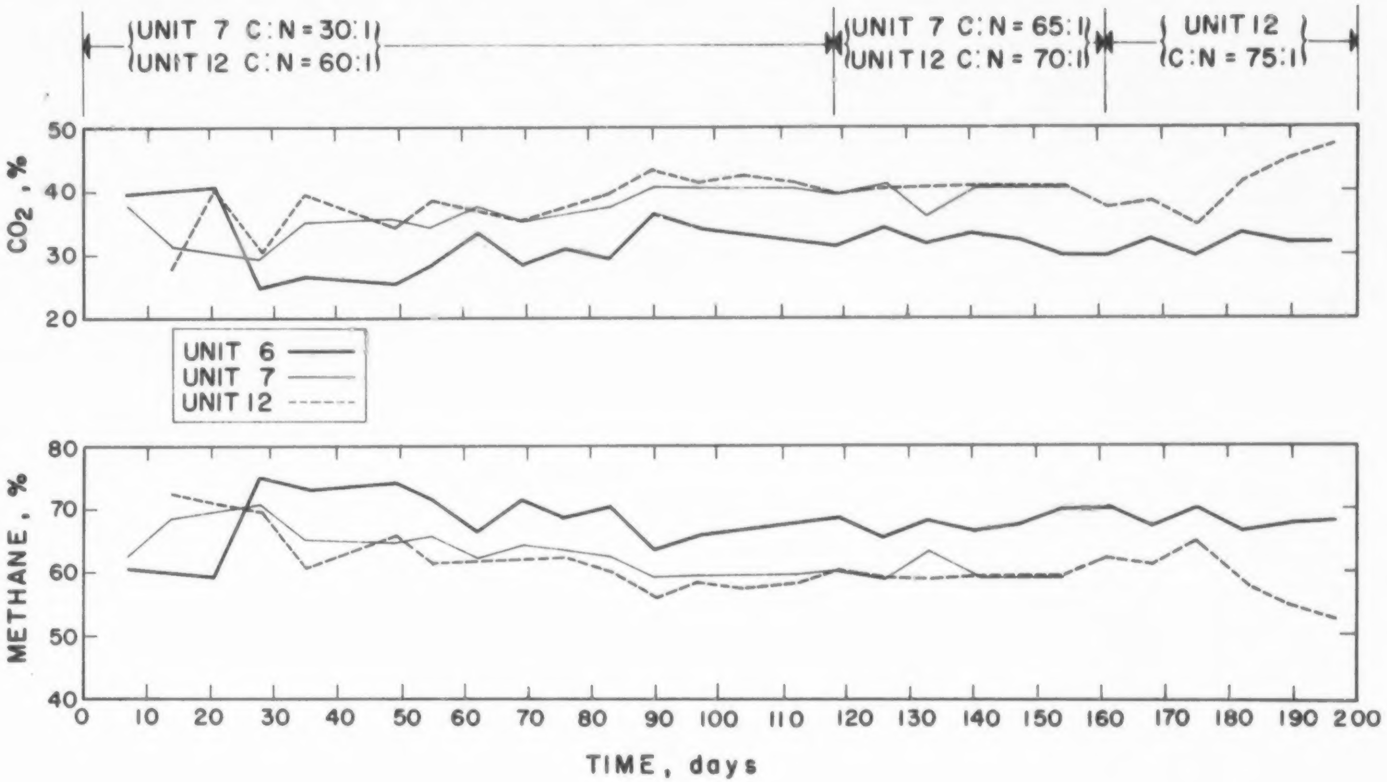

FIGURE 18. GAS COMPOSITION OF COMBINED WASTES DIGESTION

Judged on the basis of $CH_4:CO_2$ ratio, gas quality would be lower, inasmuch as in the present experiment the CH_4 content of gas from the "solid wastes" digesters averaged about 7 percent lower than that of gas from the sludge digester.

Experimental Series IV: Addition of Wood to Digesters

Introduction. Wood was made a subject of the study because it constitutes the bulk of the organic material in demolition rubble. Monterey pine wood was chosen as the test material because it is commonly used in construction and furnishing. Of greater weight in the consideration, however, was the matter of the possible presence of toxic agents in pine. Many types of wood are used for construction purposes, and one type varies considerably from another in nature and concentration of its noncellulose components. These components include lignin, waxes, fats, resins, gums, and many substances which might be toxic to anaerobic cultures. Since Monterey pine contains a relatively high proportion of these substances, it could have a greater "toxic potential" than other wood species. Plans call for the future investigation of two other potentially toxic types of wood, namely, redwood and cedar; and of one usually considered as being nontoxic, namely, white fir.

Procedure. Four digesters were utilized in the study. Digesting sludge obtained from a nearby sewage treatment plant was used as starting culture. The wood was ground to a fine powder by passing it through a Wiley mill equipped with a 1/8 in. screen. During the first 33 days, 10 percent of the feed to the digesters was in the form of wood. The percentage was raised to 20 percent in the succeeding 31 days, and to 30 percent in the following 53 days. During the final 21 days, the loadings were as follows:

Unit 1 — 30 percent wood, 70 percent sewage sludge
Unit 2 — 40 percent wood, 60 percent sewage sludge
Unit 3 — 50 percent wood, 50 percent sewage sludge
Unit 4 — 60 percent wood, 40 percent sewage sludge

Since this experiment was run simultaneously with the previous experiment, Unit 6 was made to serve as the control for the present as well as the previous experiment. The digesters were mixed on a schedule of 1.5 minutes per hour throughout the course of the experiment.

Results. The effect of wood loading on gas production provided very revealing information on the digestibility of wood. According to the curves in Figure 19, in which are plotted data on gas generation, about 0.075 cubic foot of gas was produced per cubic foot digester volume per day in the control digester, while that in the wood-fed digesters was consistently lower in almost direct proportion to the percentage of wood in the feed. For example, when the feed contained 20 percent wood, gas production was about 20 percent less than that in the control, and at 30 percent wood loading the gas production dropped to 30 percent below that in the control. This trend continued in the final phase, in which the wood portion was increased to 60 percent of the feed. It is obvious, then, that if any digestion of the wood did occur, it did not proceed beyond the acid production stage. Although less obvious, the same trend occurred in the production of gas per unit weight of volatile solids destroyed, as is shown by the curves in Figure 20. According to the curves in Figure 20, a significant drop in gas produced per pound of volatile solids destroyed occurred when wood replaced sludge as a substrate. Visual examination of the digesting sludge indicated little, if any, change in appearance of the wood. However, the association between proportion and efficiency is not clearly defined. This lack of clarity may be attributed to sampling problems which developed during the course of the experiment.

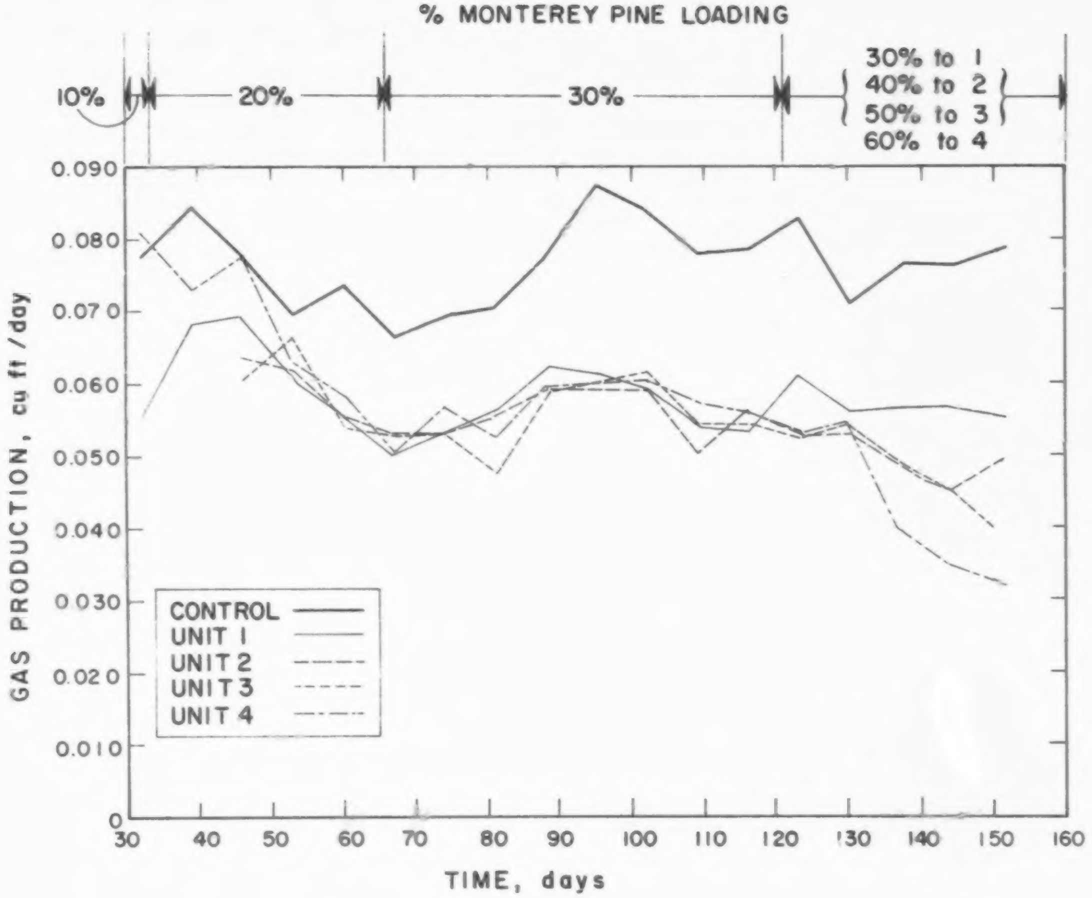

FIGURE 19. GAS PRODUCTION OF WOOD-FED UNITS

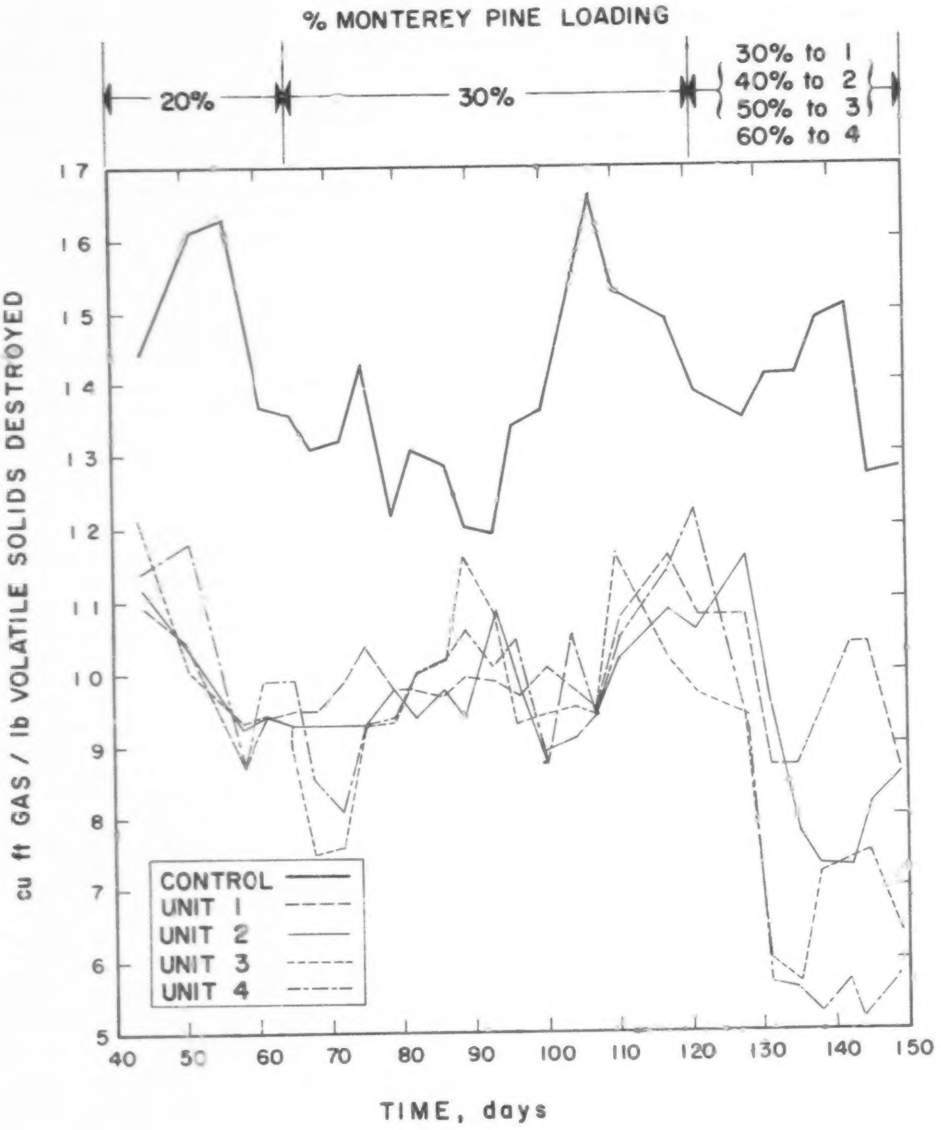

FIGURE 20. EFFICIENCY OF WOOD DIGESTION

Removing the 100-mℓ sample of digested sludge each day proved to be a particularly difficult task in this experiment. The wood-laden sludge settled with such rapidity at the cessation of the presampling mixing that by the time withdrawal of the sample was underway, a large portion of the sludge had already resettled. No satisfactory method of overcoming this problem was found, and as a result there is no question but that the data pertaining to solids reduction in this experiment have a limited degree of accuracy.

Assuming the samples to be representative despite the sampling problem, then the solids destruction data would indicate good digestion of wood. According to the information in Table 35, in which are listed data on solids reduction, about 70 percent of the volatile solids and 60 percent of the total solids (at 30 percent wood loading) were destroyed.

Similarly, results on cellulose removal (shown in Table 36) would seem to indicate a partial degradation of wood. (The table lists the input of cellulose made by way of wood and by sludge.) If the data in Table 36 are taken at face value, then with the cellulose contribution by wood at 0.892 gram per day, the digested residue had a cellulose content of 0.381 to 0.501 g/100 mℓ. Such results would lead to the conclusion that about one-half the wood was decomposed. However, the visually obvious buildup of undigested wood in the sludge belies these data.

Because of their reliability, the data on acid-base equilibria are of greater significance in this experiment than are those on solids destruction. Inasmuch as alkalinity and volatile acid determinations were routinely made on the supernatant, the sampling problem was of no consequence. According to data listed in Table 37, increase in percentage of wood in the loading was not accompanied by an increase in volatile acid production. This fact would indicate that the wood was inert to digestion. Average alkalinity in the digesters receiving wood were approximately 2200 mg/ℓ (at 30 percent wood loading). During this period, the control averaged 2740 mg/ℓ (see Figure 14). The lower alkalinity in the digesters fed wood would be expected on the basis of the 30 percent decrease in sludge feed.

Results concerned with composition of gas (listed in Table 38) were those to be expected from a digestion process. The methane content was approximately 70 percent, and the CO_2 content 30 percent. On the basis of previous experimental results showing that digestible carbonaceous feeds alter the gas composition significantly, it is apparent that the wood was not digested.

Conclusions. It may be concluded, then, that Monterey pine is inert to anaerobic digestive processes, being neither degradable nor toxic. The problem encountered in sampling suggests that pumping and circulation of wood-laden sludge might be difficult.

TABLE 35

SOLIDS REDUCTION IN DIGESTERS FED MONTEREY PINE WOOD

Day	Loading Percent of Volatile Solids as Monterey Pine	Unit 1		Unit 2		Unit 3		Unit 4	
		Total %	Volatile %	Total %	Volatile %	Total %	Volatile %	Total %	Volatile %
13	10	54.8	68.5					54.0	68.1
16	10	53.8	67.7					54.2	68.4
20	10	56.8	69.6					57.0	70.0
24	10	57.0	70.0					57.3	70.2
27	10	57.7	70.9					58.3	71.6
30	10	50.4	64.4					51.2	65.3
34	20	53.1	67.9	53.0	67.6	52.7	67.3	53.3	68.1
41	20	52.9	65.9	53.0	66.1	53.2	66.5	49.0	61.1
48	20	56.2	70.2	56.1	70.0	56.3	70.2	57.1	71.3
51	20	56.0	70.5	54.8	69.2	55.5	69.9	55.8	70.5
55	20	55.3	69.5	56.0	70.2	56.0	70.2	56.1	70.6
58	20	61.0	73.6	60.7	73.4	64.8	78.0	63.2	76.1
62	20	58.3	70.4	62.3	74.1	64.6	77.8	66.4	80.1
65	30	61.4	74.1	61.4	74.0	63.9	77.1	65.3	78.7
69	30	65.2	78.7	64.1	77.3	64.4	77.5	64.8	78.1
72	30	65.4	77.0	62.9	74.1	63.1	74.3	64.6	76.1
76	30	66.2	78.1	65.3	77.0	61.3	72.1	62.8	74.1
79	30	62.4	73.5	56.9	67.0	55.5	65.4	59.6	70.2
83	30	63.5	74.2	62.6	73.2	60.3	70.4	63.0	73.8
86	30	58.7	68.6	59.6	69.7	61.4	71.9	57.5	67.4
90	30	62.8	73.6	58.2	68.1	61.0	71.3	59.2	69.3
93	30	59.5	69.1	62.4	72.9	60.2	70.5	55.1	64.6
97	30	59.1	67.0	58.2	68.1	61.0	71.3	63.3	74.2
100	30	57.3	65.2	54.3	63.5	51.5	60.3	58.9	68.9
107	30	55.4	63.9	52.6	62.2	53.4	62.9	48.7	57.5
118	30	54.2	69.8	48.1	56.6	58.1	68.8	45.8	54.1
Avg. (65-118)		60.9	71.8	59.0	69.8	59.6	69.5	59.1	69.8
Loading to Units Changed (Unit 1 – 30%, 2 – 40%, 3 – 50%, 4 – 60%)									
121		71.0	80.0	70.4	77.0	72.9	80.1	79.2	85.5
125		71.2	80.2	75.0	82.2	76.9	84.4	81.2	87.6
128		65.6	74.1	69.4	75.9	69.7	76.4	75.2	81.0
132		59.5	67.1	61.4	67.3	68.2	74.8	70.9	76.5
135		58.0	65.5	56.8	62.2	58.9	64.6	-	-
139		69.3	78.1	64.4	70.5	69.0	75.8	71.1	76.9
142		54.7	61.6	58.0	63.4	61.8	67.9	67.1	72.5
Avg.		64.2	72.4	65.1	71.2	68.2	74.9	74.1	80.0

TABLE 36

CELLULOSE DECOMPOSITION IN DIGESTERS FED MONTEREY PINE

Day	Unit 1 Digester Residual		Unit 2 Digester Residual		Unit 3 Digester Residual		Unit 4 Digester Residual	
	g/100 mℓ	Removal %	g/100 mℓ	Removal %	g/100 mℓ	Removal %	g/100 mℓ	Removal %
I. Cellulose Input/day: 1.215 g (from sludge), 0.892 g (from wood)								
104	0.521	75.3	-	-	0.560	73.4	0.506	76.0
110	0.464	78.0	0.610	71.0	0.591	72.0	0.517	75.5
117	0.260	87.7	0.397	81.2	0.381	81.9	0.345	83.6
124	0.278	86.8	0.338	84.0	0.472	77.6	0.392	81.4
Avg.	0.381	81.9	0.448	78.7	0.501	76.2	0.440	79.1
II. Change of Cellulose Input/day to Units as follows:								
	Sludge – 1.215 g Wood – 0.892 g		Sludge – 1.041 Wood – 1.184		Sludge – 0.868 Wood – 1.480		Sludge – 0.695 Wood – 1.780	
131	0.350	83.4	0.729	67.2	0.790	66.4	0.867	65.0
138	0.782	62.9	0.527	76.3	0.836	64.4	0.702	71.6
Avg.	0.566	73.2	0.628	71.8	0.813	65.4	0.785	68.3

TABLE 37

ACID-BASE PARAMETERS IN WOOD-FED DIGESTERS

Day	Loading Percent of Volatile Solids as Monterey Pine	Alkalinity, mg/ℓ				Volatile Acids, mg/ℓ				pH, (weekly average)			
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 1	Unit 2	Unit 3	Unit 4	Unit 1	Unit 2	Unit 3	Unit 4
13	10	2949	-	-	3005	68	-	-	61	7.25	7.45	7.45	7.27
16	10	2950	-	-	2930	64	-	-	100	-	-	-	-
20	10	3006	-	-	3073	125	-	-	9	7.27	7.39	7.39	7.29
23	10	2950	-	-	3019	33	-	-	33	-	-	-	-
27	10	3021	-	-	3051	29	-	-	22	7.31	7.37	7.46	7.33
30	10	2834	-	-	2857	26	-	-	36	-	-	-	-
34	20	2830	-	-	2859	-	39	55	37	7.23	7.32	7.37	7.26
41	20	2680	3378	2671	2726	37	60	62	35	7.21	7.28	7.36	7.22
48	20	2541	3010	3245	2560	57	50	68	-	7.28	7.30	7.30	7.18
51	20	2487	2949	3140	2560	33	31	27	16	-	-	-	-
56	20	2341	2755	2894	2388	37	34	32	25	7.22	7.31	7.33	7.24
58	20	2418	2800	2915	2441	19	40	35	19	-	-	-	-
62	20	2360	2742	2809	1408	26	42	56	38	7.24	7.26	7.28	7.24
65	30	1950	2600	2625	2303	-	-	-	-	-	-	-	-
69	30	2320	2510	2482	2230	14	44	14	16	7.17	7.13	7.15	7.09
72	30	2330	2518	2461	2290	20	26	59	24	-	-	-	-
79	30	2248	2354	2332	2230	30	51	9	28	7.13	7.24	7.20	7.13
86	30	2250	2365	2400	2261	56	5	12	19	7.10	7.16	7.13	7.11
90	30	2172	2318	2270	2210	-	-	-	-	7.12	7.18	7.16	7.12
93	30	2075	2154	2222	2138	32	50	23	41	-	-	-	-
97	30	2140	2198	2234	2130	9	9	12	16	7.11	7.15	7.13	7.08
100	30	2079	2154	2200	2162	25	41	36	36	-	-	-	-
104	30	2100	2122	2212	2121	23	36	23	21	7.08	7.12	7.13	7.10
107	30	2000	2139	2147	2112	22	27	-	22	-	-	-	-
111	30	2062	2135	2140	2099	14	21	21	44	7.11	7.10	7.08	7.09
114	30	2070	2110	2136	2020	17	19	19	5	-	-	-	-
118	30	2100	2121	2109	2103	5	25	5	7	7.15	7.10	7.07	7.11
Avg. (65-118)		2135	2271	2284	2172	22	30	21	23	7.12	7.15	7.13	7.10
Loading to Units Changed (Unit 1 – 30%, 2 – 40%, 3 – 50%, 4 – 60%)													
121		2029	2060	2068	2009	18	18	20	18	-	-	-	-
125		1995	1980	1975	1930	27	5	20	14	7.19	7.16	7.17	7.17
128		1981	1990	1950	1900	12	12	18	9	-	-	-	-
132		1980	1963	1909	1815	19	31	14	26	7.10	7.10	7.08	7.06
135		1968	1987	1849	1670	-	12	12	5	-	-	-	-
139		1920	1840	1781	1645	19	7	21	12	7.12	7.08	7.10	7.10
Avg.		1979	1970	1922	1828	19	14	18	14	7.14	7.11	7.12	7.11

TABLE 38

GAS COMPOSITION IN WOOD-FED DIGESTERS

Day	Loading Percent of Volatile Solids as Monterey Pine	Methane, %				CO₂, %			
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 1	Unit 2	Unit 3	Unit 4
14	10	72.6	-	-	77.8	27.4	-	-	22.2
29	10	68.4	-	-	68.0	31.6	-	-	32.0
35	20	-	69.0	70.9	72.4	-	31.0	29.1	27.6
42	20	71.5	80.4	80.8	71.4	28.5	19.6	19.2	28.6
49	20	75.5	71.1	83.0	74.2	24.5	28.9	17.0	25.8
56	20	69.9	67.0	65.6	68.8	30.1	33.0	34.4	31.2
63	20	69.8	68.0	66.4	70.0	30.2	32.0	33.6	30.0
70	30	66.1	65.4	64.3	65.4	33.9	34.6	35.7	34.6
77	30	67.4	65.7	64.7	67.3	32.6	34.3	35.3	32.7
84	30	67.5	68.5	65.6	66.3	32.5	31.5	34.4	33.7
92	30	67.2	65.0	62.5	65.6	32.8	35.0	37.5	34.4
99	30	72.9	63.6	66.8	68.5	27.1	34.4	33.2	31.5
106	30	66.1	67.9	67.2	65.7	33.9	32.1	32.8	34.3
113	30	67.6	67.9	68.3	68.5	32.4	32.1	31.7	31.5
120	30	67.6	67.5	66.8	67.6	32.4	32.5	33.2	32.3
Avg. (70-120)		69.3	68.2	68.7	69.2	30.7	31.8	31.3	30.8
Loading to Units Changed (Unit 1 – 30%, 2 – 40%, 3 – 50%, 4 – 60%)									
127		67.8	69.7	70.5	67.3	32.2	30.3	29.5	32.7
135		69.5	70.5	68.7	69.5	30.5	29.5	31.3	30.5
141		72.8	70.3	70.5	70.7	27.2	29.7	29.5	29.3
Avg.		70.0	70.2	69.9	69.2	30.0	29.8	30.1	30.8

VIII. COMPOSTING

INTRODUCTION

Traditionally, composting has been regarded as a way of upgrading domestic refuse into something that is useful as a soil conditioner, and therefore as an ideal method for solving the solid wastes treatment problem. However, of the 14 plants constructed to make compost from domestic refuse in the United States since World War II, only four are in operation, and they accept and convert the wastes from but 50,000 of the nation's 200,000,000 people. Although the reasons for the failure of composting to take hold in this country are manifold in nature, undoubtedly the major contributing factors are the unfavorable economics of composting systems now available and the unrealistic approaches made to solve the economic problems besetting the practice.

Originally, it was thought that the cost to the city for disposing of refuse by composting would be less than that of disposal by burying or incineration, inasmuch as it was expected that the sale price of the compost would more than cover the cost of the processing. However, in practice, it was found that, aside from the fact that a market for the compost product either is nonexistent or insignificant in extent, the weight or volume of salable compost after processing often is less than one-half of the original input. This loss in volume or weight was due to two factors. First, of a ton of incoming refuse, from 200 to 600 pounds are in the form of noncompostable material. Secondly, the composting process itself reduces the volume and weight of the raw refuse by an additional fourth to a third. Furthermore, the cost of the operations of sorting, grinding, sieving, screening, ballistic separation, and the like, all combine to make the finished compost expensive.

Rationale

Inasmuch as the history of failure of composting in refuse disposal has been due principally to economics, the obvious approach would be to develop an inexpensive system and to discard the concept of financing the operation through sale of the product. This reasoning led to the development of a concept of composting based on the rationale that land should be an essential part of the treatment, but in a manner such that it need not be permanently dedicated to wastes disposal, as is landfill. According to this rationale, the land would serve as a means of processing wastes rather than solely as a means of disposing of them. A second consideration in the rationale is that advantage be taken of the growth-decay cycle prevailing in the soil, i.e., that the biooxidation phase of the cycle be adapted to the oxidation and stabilization of the organic matter in the wastes. In this second phase, two approaches can be taken into consideration. In one, the land would be loaded to the limit of its ability to accept the wastes without disrupting the growth-decay cycle. (Exceeding this limit would result in the establishment of conditions leading to the production of objectionable odors and other nuisances.) In the second, the land would be used for cropping as well as treatment, i.e., it would be loaded on a seasonal basis.

Low-Cost Biostabilization System

The system which was developed from the concept was one involving two key steps, namely, minimal processing of the wastes and immediate incorporation of the processed wastes into the soil. For convenience of reference, the system is designated in this report as "low-cost biostabilization." The term biostabilization is used because situations are included which range from those in which the refuse is incorporated into the soil without prior treatment other than a minimum of segregation and grinding (less elegantly referred to as "garbage farming") to those in which a minimum of composting takes place before incorporation.

In practice, a given plot of land would receive a loading of ground raw and unsegregated (or, if need be, roughly composted) refuse once or twice each year throughout the time in which the site is dedicated to wastes disposal. The frequency of the loading would be a function of the rate of decomposition or stabilization of the wastes in the soil. When the time comes to divert the land to another use, loading would be stopped and the land allowed to recover. The nondegradable material remaining exposed on the soil would be removed and buried elsewhere. Inasmuch as only the top foot or two of the land would be involved, settling would be a negligible factor, and the land could be put to its new use immediately.

Objectives

The objectives of the research are logical projections from the two key steps (minimal processing and incorporation into the soil) in the low-cost biostabilization system. In relation to Step 1, the objective is to determine the minimum amount of processing needed prior to incorporating the wastes into the soil. In line with this objective, the research is concerned with determining whether or not there is a response difference with the material being in the form of raw ground refuse or of rough quality compost. If the results show that a composting step is needed, the investigation will be directed toward determining the extent or degree of composting required.

Objectives related to Step 2 deal with amount and timing of loading and with the effects of cultural operations. In relation to loading, the aim is to 1) arrive at an estimate of the extent to which land can be loaded without seriously impairing the long-term usefulness of the land; and 2) determine what amount and timing of loading would be compatible with cropping a given parcel of land as well as using it for wastes disposal. In relation to effect of cultural operations, an attempt is to be made to assess the need for the use of chemical fertilizers, the imposition of pH control, and the application of other comparable farming factors.

THE EXPERIMENTS

Experimental Setup

The experimental work is being carried on at the Davis campus of the University. A portion of the domestic solid wastes generated in on-campus apartments and some of the high paper-content wastes from classrooms and offices are diverted to the site of the "low-cost biostabilization" experiments for use as raw material in the study. The refuse is processed with the use of materials handling equipment and shredded in a John Deere 110-A hammermill capable of processing about 100 pounds of raw refuse per man-hour. The shredder and a part of the materials handling equipment are shown in Figure 21. When not used directly, the shredded refuse is composted in a 6-ft diameter by 5-ft long pilot composting drum, shown in Figure 22.

The prepared material is applied to experimental plots, each of which is 5 ft by 20 ft in size. An overview of the field on which the prepared material is applied is shown in Figure 23. At the time the picture shown in the figures was taken, only the summer plots have had material applied to them. Plots in the background await compost and refuse in the subsequent season. In Figure 24 is shown a close-up of a plot loaded at the rate of 200 tons per acre-year. The loading rates are given in Table 39.

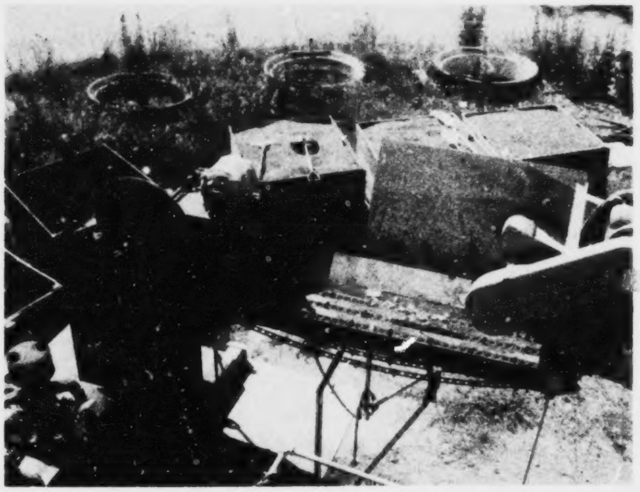

FIGURE 21. SMALL REFUSE SHREDDING FACILITY USED TO PREPARE ON-CAMPUS DOMESTIC REFUSE FOR COMPOSTING OR FOR DIRECT APPLICATION TO THE EXPERIMENTAL PLOTS

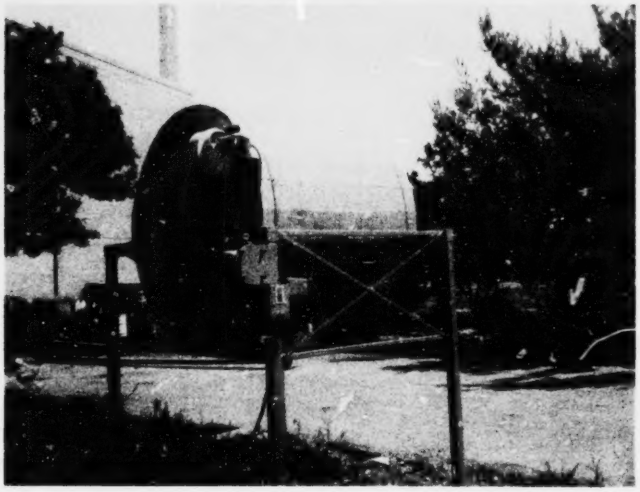

FIGURE 22. COMPOST DRUM, 5 FT. LONG 6 FT. DIAMETER, BATCH OPERATION

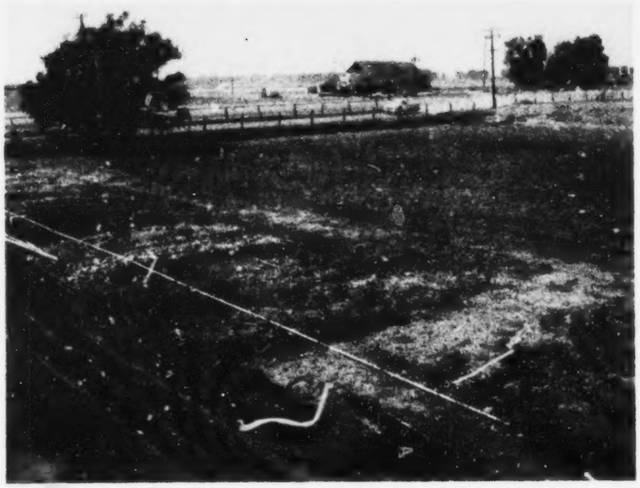

FIGURE 23. EXPERIMENTAL FIELD PLOTS

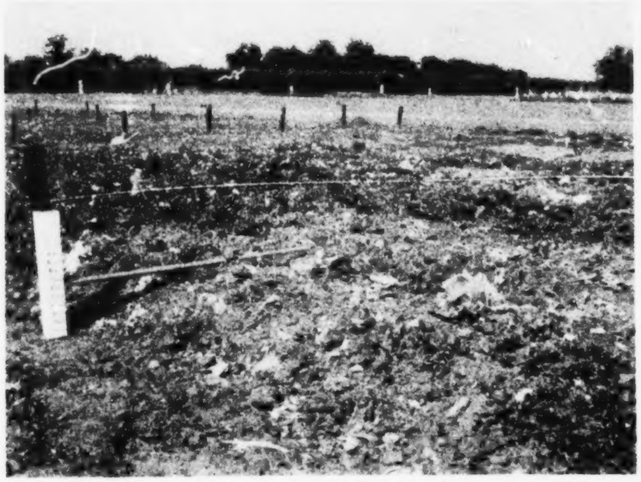

FIGURE 24. CLOSE-UP OF THE PLOT RECEIVING 200 TON / ACRE / YEAR OF ROUGH COMPOST

TABLE 39

LOADING RATES FOR SHREDDED REFUSE AND ROUGH COMPOST ON EXPERIMENTAL PLOTS

Material	Loading Rate (tons dry matter/acre-year)					
Raw Shredded Refuse	0	50	100	200	300	400
Rough Compost	0	50	100	200	300	400

There are four series of plots. Each plot receives solid wastes once each year. Wastes are applied to one series of plots in the summer, a second series in the autumn, a third series in the winter, and a fourth series in the spring. This arrangement represents the real-life situation in which refuse is produced and in which wastes must be processed the year-round.

The organic material is spread on the land surface, tilled in with a heavy-duty tiller, and then is heavily irrigated. This procedure had to be changed somewhat when making the 300 and 400 tons per acre-year applications. With such loadings, it was necessary to remove the top six inches of soil before applying the refuse, return the soil to the top of the applied wastes, and, finally, to till and mix soil and refuse. Therefore, should high loading rates prove feasible, it will be necessary to develop the specialized equipment needed to carry out these steps on a practical scale.

Progress

As of July 1968, only the summer application of materials has been made to the field plots. Compost presently is being prepared for the fall application, and laboratory tests are underway to evaluate the response of the land to the loadings. The soil response studies, being made cooperatively with a soils physicist from the Vegetable Crops Department, consist of chemical and physical measurements. Chemical determinations are being made of nitrogen, phosphorus, carbon, and total salts. The salts determinations are made by means of electrical conductivity. Physical tests include bulk density, rate of breakdown, and consideration of the land and its applied wastes.

IX. WET OXIDATION

INTRODUCTION

As discussed in greater detail in the First Annual Report, the basic reaction involved in wet oxidation and its application to organic wastes, extends back over fifty years of related work. Fundamentally the process is one of oxidizing aqueously dispersed organic material with molecular or atmospheric oxygen under superatmospheric pressures and at elevated temperatures. In its utilization, the process has been applied with various disposal or recovery objectives in mind. Thus, in the application, the process has been carried out at levels of degradation approaching those of incineration at one extreme and of biological processes at the other. As such, wet oxidation has avoided the air pollution and preparatory problems normally associated with dry combustion and the environmental problems encountered in biological oxidation or digestion.

Wet oxidation has been used in the pulp and paper industry for the treatment of spent pulping liquor to recover energy and inorganic chemicals and to abate stream pollution. For example, a 500-ton-per-day pulp mill in Norway uses the process for the recovery of thermal energy in spent pulping liquor solids.

In the treatment of municipal wastes, wet oxidation has been applied for the elimination of health hazards and nuisance conditions related to sewage sludge disposal and for the economical reduction of the volume of this waste. The process presently is being utilized for the disposal of one to 200 tons per day of municipal solids in five cities in the United States. It should be noted, however, that recently the Metropolitan Sanitary District of Chicago, Illinois, announced plans for phasing out their existing digested sludge disposal facilities, including the 200-ton-per-day West-Southwest wet oxidation plant, within ten years in favor of using this sludge for land reclamation. This proposed change was dictated primarily by economic considerations which indicated that sludge-digestion land reclamation would cost $15-16 per ton (day basis) in contrast to $49-60 per ton (day basis) for their present sludge-treatment disposal methods.

Recent research efforts have been directed toward low-temperature and low-pressure oxidations of sewage sludge [71] and characterization of the resultant oxidation products [72]. Reaction temperatures of 150° to 175°C and pressures of 150 to 300 psi have been utilized to partially oxidize sludge to sterile, easily dewatered slurries suitable for ultimate disposal after as little as 10 percent COD reduction. Lower levels of oxidation can be attained at lower capital and operating costs than for higher levels; however, there are greater volumes of residual solids left for ultimate disposal at lower levels of oxidation. Typical installation and operating costs for a low-temperature and low-pressure sewage sludge oxidation process are shown in Table 40.

Rationale

The disposal of wastes materials by wet oxidation has been complemented in many instances by the recovery of thermal and mechanical energy and inorganic chemicals. In this regard, however, the recovery of organic chemicals has largely been neglected. The recovery of such chemicals, particularly those of commercial utility, and, in addition, the utilization of solid wastes materials for the production of such chemicals, is the concern of this research team.

The overall promise of wet oxidation as currently being utilized for the disposal of wastes materials and the potential of the reaction for the production of organic chemicals, as indicated by studies at this and other laboratories, provides the general justification for this approach. A more implicit justification is that

TABLE 40

TYPICAL COSTS FOR LOW-TEMPERATURE AND LOW-PRESSURE WET OXIDATION OF SEWAGE SLUDGE [71]

Item	Raw Sludge Costs[a]		Digested Sludge Costs[b]	
	With Vacuum Filter	Without Vacuum Filter	With Vacuum Filter	Without Vacuum Filter
Installed Plant Cost	$ 330,000	$ 250,000	$ 290,000	$ 225,000
Average Operating Cost per Ton				
Electricity	$ 1.92	$ 1.44	$ 1.48	$ 1.05
Boiler Fuel	2.25	2.25	1.54	1.54
Boiler Feed Water	0.06	0.06	0.05	0.05
Effluent Water	0.08	0.07	0.07	0.06
Maintenance	1.08	0.83	0.97	0.75
Cost per Ton Solids Processed	$ 5.39	$ 4.65	$ 4.11	$ 3.45

[a] Costs are based upon a 1000-lb sludge solids per hour operation processing a 5 percent slurry which contains 67 percent volatile solids

[b] Costs are based upon a 1000-lb sludge solids per hour operation processing a 6 percent slurry which contains 50 percent volatile solids

presently wet oxidation is being applied to aqueous dispersions of organic wastes which technically or economically would not be practicable to treat by other means. A utilization rather than a disposal approach to these and other applications may remove such limitations; i.e., a utilization approach would consider all organic wastes materials, regardless of form or condition, to be technically suited to the reaction and economically justified in terms of organic chemical production.

The reaction in question is a rather complex one involving hydrolysis and pyrolysis, as well as oxidation. As such, the reaction initially degrades wastes materials to simpler organic compounds and then to carbon dioxide and water. This intermediate level of degradation is of primary concern in this study because it dictates both the quality and quantity of potential organic chemical production and the design of potential processes. The utilization of a wide range of solid wastes materials allows control of the organic content and concentration of the reaction mixture. Such control, coupled with appropriate reaction conditions, provides the basis for organic chemical production.

Objectives

The long-term objective of this research team is the conversion of solid wastes materials to organic chemicals of commercial potential under conditions of wet oxidation. More specifically this will include: a) a study of the basic reaction relationships of wet oxidation, particularly as related to the production of organic chemicals; b) the application of wet oxidation under predetermined reaction conditions to various organic wastes materials to determine the organic chemical production potential of a particular waste or group of wastes; c) the utilization of wet oxidation under reaction conditions specific for the production of a particular organic chemical or group of chemicals to provide the bases for potential process designs; and d) the development of pilot and full-scale process designs for the production, isolation, and utilization of organic chemicals formed from solid wastes materials under conditions of wet oxidation.

EXPERIMENTAL APPROACH

The experimental part of this study is divided into three phases which will be considered in a sequential manner. Phase I, which is now in progress, probably will be completed during the current research year with the subsequent initiation of Phase II; Phase III will not be undertaken within the immediate future.

Phase I — Determination of Basic Reaction Relationships

The initial stage of this phase was devoted to modification and to design and fabrication of equipment needed to accommodate a laboratory-scale wet oxidation process, shown schematically in Figure 25. Reactions are carried out on a batch basis in a steam-jacketed reactor augmented by a high-pressure steam boiler, automated temperature controls, and an integrated instrumentation complex (shown in Figure 26) for monitoring and recording reaction parameters. An extension for this reactor (shown in assembled form in Figure 27) was built to provide a disengagement zone above the reaction medium and to allow entrance of a hydraulically-operated turbine agitator. Air at pressures up to about 500 psi is supplied to the reactor by an air compression and storage regulation system (shown in part in Figure 28) constructed for this purpose. Off-gases from the reactor are passed through a condenser, expanded across a back-pressure control valve, scrubbed in an aqueous sodium bicarbonate spray tower, and measured volumetrically with a turbine flowmeter-indicator system. Periodic on-stream determinations of the scrubbed off-gas composition are made by gas-solid chromatography.

Laboratory-scale reactions were carried out with hammermilled, air dried white fir wood to establish basic reaction relationships and to relate their results to those of earlier studies at this laboratory. Reaction parameters under

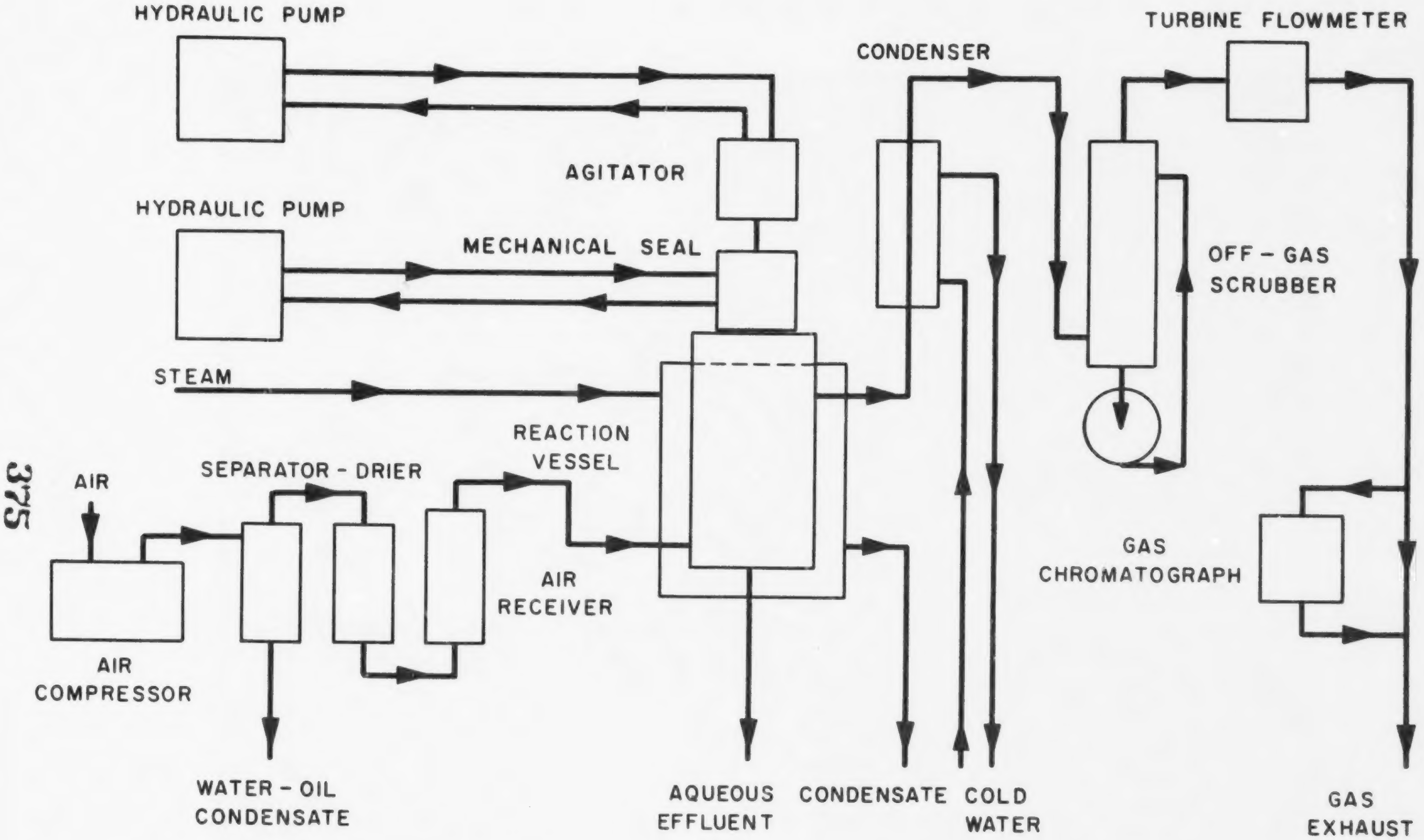
HYDRAULIC PUMP
HYDRAULIC PUMP
STEAM
AIR
AIR COMPRESSOR
SEPARATOR - DRIER
WATER - OIL CONDENSATE
AIR RECEIVER
REACTION VESSEL
AGITATOR
MECHANICAL SEAL
AQUEOUS EFFLUENT
CONDENSATE
CONDENSER
COLD WATER
OFF - GAS SCRUBBER
TURBINE FLOWMETER
GAS CHROMATOGRAPH
GAS EXHAUST

FIGURE 25. SCHEMATIC DIAGRAM OF BATCH WET OXIDATION PROCESS

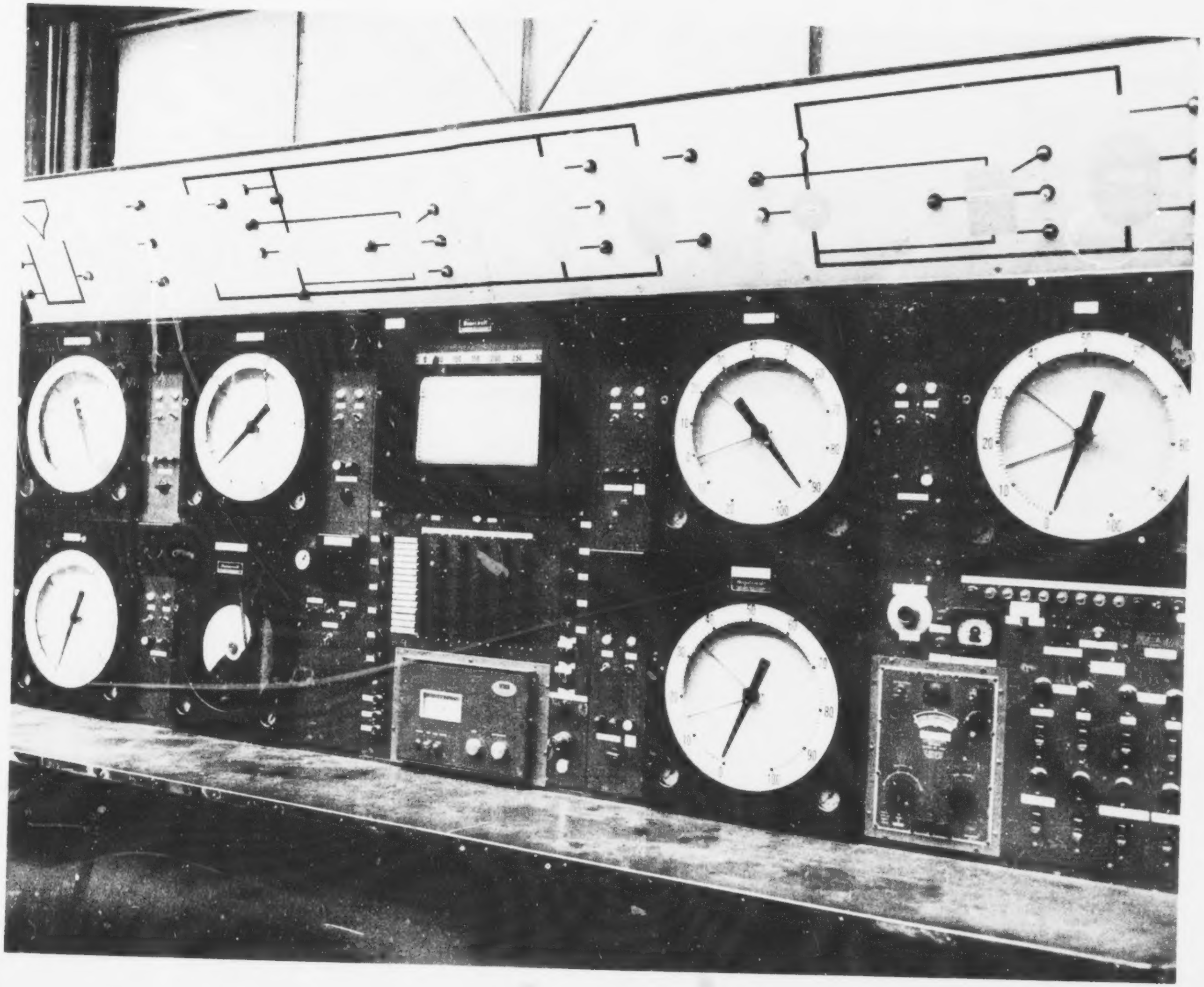

FIGURE 26. INSTRUMENTATION COMPLEX FOR MONITORING AND RECORDING REACTION PARAMETERS

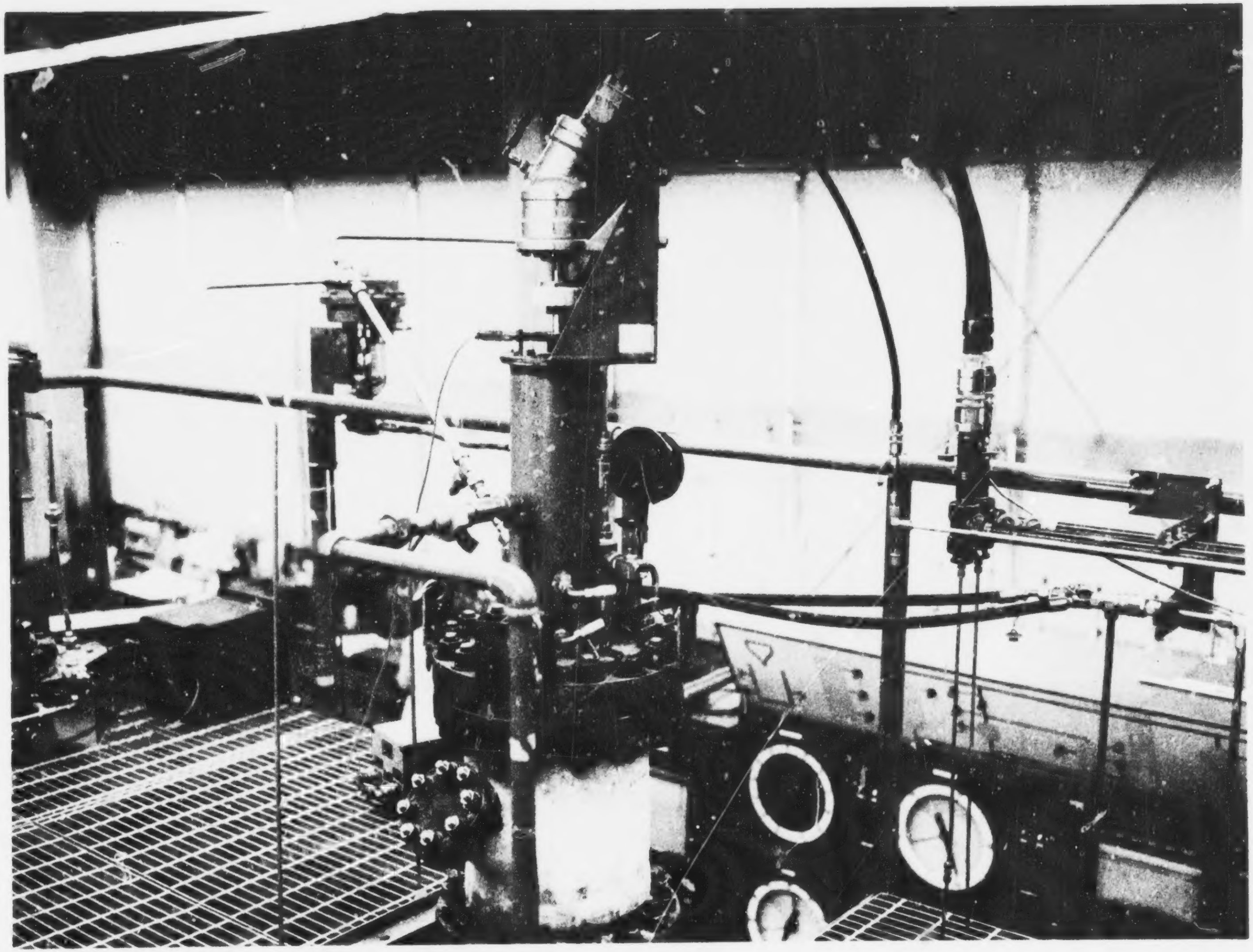

FIGURE 27. REACTOR EXTENSION AND AGITATOR DRIVE IN ASSEMBLED FORM

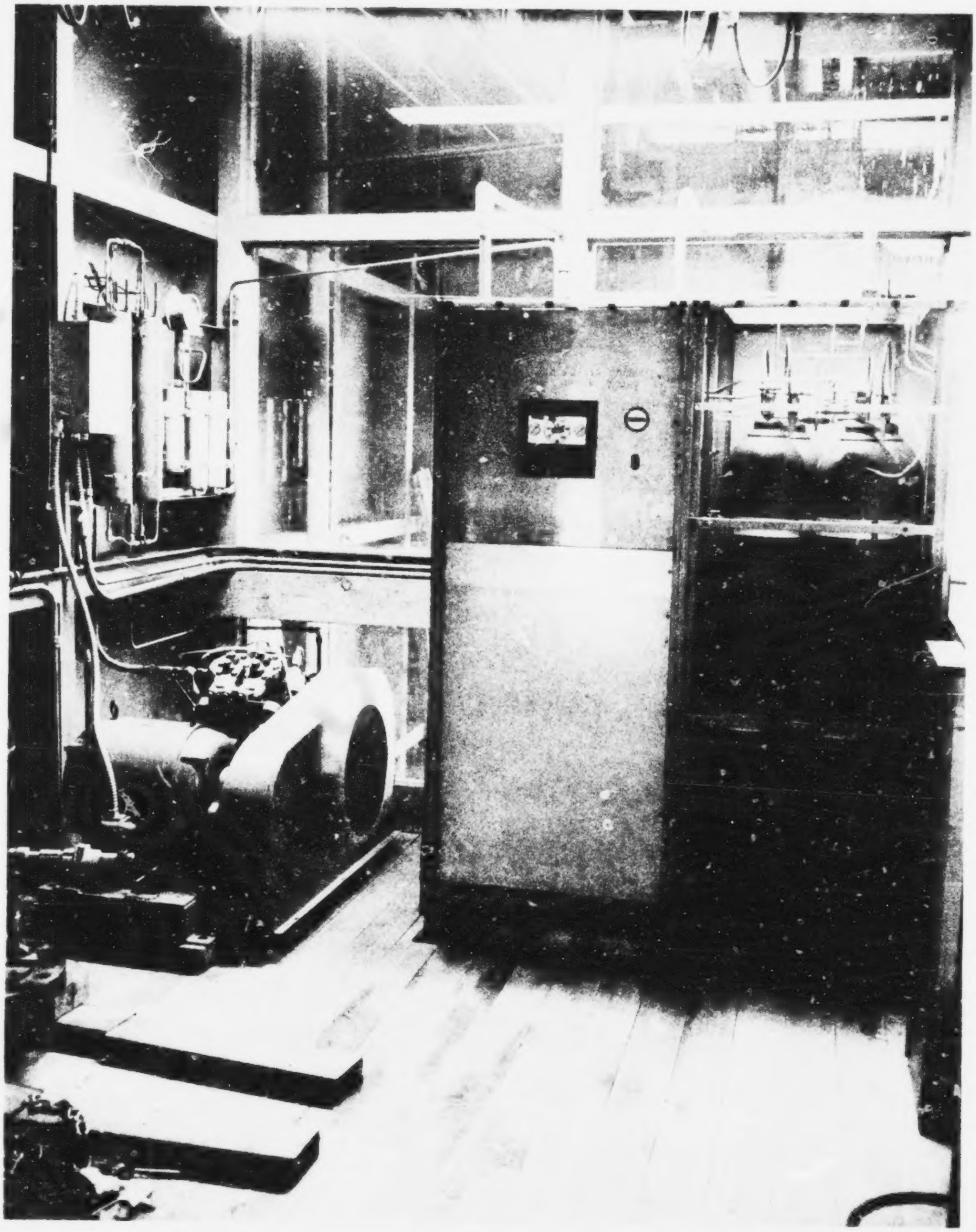

FIGURE 28 AIR COMPRESSION AND STORAGE SYSTEM

consideration included time, temperature, total and partial pressure, solids concentration, and agitation. A summary of reaction conditions utilized in Phase I oxidation reactions is presented in Table 41. Oxygen consumption and carbon dioxide-carbon monoxide formation were followed by chromatography and pressure-volume relationships. Liquid and solid components of the reaction mixtures were separated by vacuum filtration and subjected to physical and chemical analyses to establish material and energy balances. Organic chemical yields will be determined by gas-liquid chromatography.

Phase II — Oxidation of Organic Solid Wastes Materials

In this phase, the experimental techniques developed and results obtained in Phase I will be applied to work with additional organic wastes materials such as municipal wastes, agricultural residues, sewage sludge, industrial effluents, and combinations of these and other wastes.

Phase III — Process Design

This phase will assimilate the results of the preceding phases into possible process designs for the production, isolation, and utilization of organic chemicals from wet oxidation of solid wastes materials.

Results

During the period covered by this report, the activities of the research team were concerned with the completion of preparatory activities described in the preceding report [1] and with the initiation and completion of the experimental aspects of Phase I.

Most of the planned reaction equipment modification and construction was completed early in 1968 and the overall reaction system was divided into four subsystems — air, agitator, reactor, and analysis — for performance tests before undertaking trial reactions. The lightweight air compressor originally intended for the air subsystem failed repeatedly under brief periods of service and was replaced with a rebuilt, air-cooled Ingersoll-Rand compressor rated at 17 cubic feet per minute free air displacement at 2000 psi. An aftercooler had to be added to aid in excess water removal from the air, and for safety considerations the three spherical air receivers initially intended for air storage were replaced with six ICC 3AA2400 gas cylinders. After these modifications the air subsystem had a storage capacity of 1500 cubic feet of air at 2000 psi.

The electric motor drive design for the turbine agitator was abandoned in favor of a rebuilt, 5 hp Vickers hydraulic pump and motor. This arrangement allowed greater versatility and operational safety. A baffle-steady bearing subassembly was designed and constructed for the agitator to increase mixing action and to reduce excessive shaft wobble.

The reactor and related instrumentation and controls required only the replacement of some temperature and pressure sensors and the addition of an air inlet. A 1/2 ton electric overhead crane was installed above the reactor to facilitate assembly and disassembly of the reactor-agitator subsystems.

Chromatographic procedures developed in earlier studies for analysis of CO_2, N_2, O_2, and CO were adapted for continuous, on-stream sampling of reaction off-gases.

Following the subsystem checks, the overall reaction system was subjected to simulated reactions to develop appropriate control and handling procedures. Many of the procedures utilized for rapid cycle, high temperature pulping were

TABLE 41

SUMMARY OF WET OXIDATION REACTIONS OF WHITE FIR WOOD

Reaction Number	Wood g(OD)	Water g	Temperature °C	Time at Temperature min	Total Pressure psi	Air Partial Pressure psia	Air Input[a] Rate cu ft/min	Rate of Agitation rpm
WO-1-6	4,000	40,000	160	120	225	150	2	600
WO-1-7	4,000	40,000	160	120	225	150	1	600
WO-1-4	4,000	40,000	180	120	280	150	2	600
WO-1-5	4,000	40,000	180	120	280	150	1	600
WO-1-1	4,000	40,000	200	120	395	180	1	600
WO-1-2	4,000	40,000	200	120	360	150	2	600
WO-1-3	4,000	40,000	200	120	360	150	1	600
WO-1-8	4,000	40,000	220	120	470	150	1	600
WO-1-9	4,000	40,000	220	120	470	150	2	600
WO-1-10	4,000	40,000	220	120	470	150	1	600

[a] Air flow measured downstream of reactor at ambient temperature and atmospheric pressure

unsuitable in this reaction system. Included among these procedures were direct injection of preheated water into the reactor to attain rapid temperature rise, circulation of the aqueous phase of the reaction mixture through a heat exchanger for temperature control, and pressure filtration of the reaction mixture in the reactor. Indirect heating with high-pressure steam was used to bring about a rapid rise in temperature, and with appropriate control, to maintain the reaction temperature. Conversely, indirect cooling was effected with low-pressure steam from reaction temperature down to 155°C, and then with water to ambient temperature. Because of the poor control characteristics of the back-pressure control valve, total reaction pressure had to be maintained manually rather than automatically as originally planned.

Upon completion of the final shakedown stage, a series of reactions with white fir wood was carried out under the conditions indicated in Table 41. In reactions WO-1-2 to WO-1-10, reaction temperature was varied from 160° to 220°C in 20°C increments and air input from 1 to 2 cubic feet per minute at each of these temperatures while holding all other parameters constant. Air partial pressure was raised to 180 psia in reaction WO-1-1 to effect a higher initial oxygen partial pressure. Reaction WO-1-8 was duplicated in WO-1-10 because of the loss of air input control during the latter stages of WO-1-8. No further reactions were undertaken because it was thought that temperature and air input would provide the most dramatic changes in organic chemical yields and that some parameters might be more effectively evaluated in Phase II. Physical limitations of the reaction system and impending manpower losses at the beginning of the current research year were also factors in this decision.

The products from these reactions have been physically processed and have undergone or are now undergoing chemical and physical analyses. Materials balances are shown in Table 42. Energy balances have not been established as yet and will be reported at a later date. Total carbon distributions between the three reaction phases are displayed graphically as functions of temperature and air input in Figure 29.

Chromatographic and pressure-volume data related to oxygen consumption and carbon dioxide-carbon monoxide formation have been reduced to a weight basis and are presented in Table 43. Gas consumption and formation per se, and on a 100 g of solubilized carbon basis are shown graphically as functions of temperature and air input in Figures 30 and 31, respectively.

Organic chemical yields for these reactions have not been determined and will be reported at a later date.

DISCUSSION

As noted in a previous section, the production of intermediate levels of degradation in wastes materials is a primary concern of the research team concerned with wet oxidation, because such materials control both the quality and the quantity of potential organic chemical production and the design of potential processes. Partial physical and chemical results from Phase I reactions indicate that such levels were attained for wood, and that organic chemical production could be realized at a relatively low temperature and pressure.

Under the experimental conditions, the maximum yield of dissolved solids (or, in terms of this discussion, maximum total organic chemical yield) occurred with the temperature at 200°C and the air input at 2 cubic feet per minute. At this point, dissolved solids constituted 50.2 percent of the total solids input. The residual solids yield decreased and the volatilized solids yields increased with increase in temperature. Dissolved solids yields increased with temperature to maxima and then decreased. These trends held at both air input rates. With the air input at 2 cubic feet per minute, the residual and the volatilized solids yields were lower at every reaction temperature, whereas the dissolved solids yield was higher.

TABLE 42

MATERIALS BALANCE FOR WET OXIDATION REACTIONS OF WHITE FIR WOOD

Reaction Number	Reaction Influent			Reaction Effluent						
				Residual Solids			Dissolved Solids		Volatilized Solids	
	Total Solids g	Volatile Solids g	Total Carbon g	Total Solids g	Volatile Solids g	Total Carbon g	Total[a] Solids g	Total[b] Carbon g	Total[c] Solids g	Total[d] Carbon g
WO-1-6	4,000	3,972	1,849	2,703	2,683	1,213	1,302	602	73	34
WO-1-7	4,000	3,972	1,849	2,874	2,854	1,352	967	447	108	50
WO-1-4	4,000	3,972	1,849	2,161	1,977	1,009	1,516	701	302	139
WO-1-5	4,000	3,972	1,849	2,766	2,749	1,295	766	354	434	200
WO-1-1	4,000	3,972	1,849	1,856	1,822	920	1,387	641	622	288
WO-1-2	4,005	3,976	1,852	1,428	1,403	708	2,012	930	463	214
WO-1-3	4,001	3,973	1,850	2,002	1,977	1,058	1,168	540	544	252
WO-1-8	4,000	3,972	1,849	1,879	1,860	1,027	1,201	555	578	267
WO-1-9	4,000	3,972	1,849	1,525	1,510	860	1,456	673	684	316
WO-1-10	4,000	3,972	1,849	2,058	2,039	1,106	854	395	752	348

[a] Total solids weight equivalent calculated from total carbon difference and carbon content of wood

[b] Total carbon weight equivalent calculated from total carbon difference

[c] Total solids weight equivalent calculated from carbon dioxide-carbon monoxide carbon and carbon content of wood

[d] Total carbon weight equivalent calculated from carbon dioxide-carbon monoxide carbon

TABLE 42

MATERIALS BALANCE FOR WET OXIDATION REACTIONS OF WHITE FIR WOOD

Reaction Number	Reaction Influent			Reaction Effluent						
				Residual Solids			Dissolved Solids		Volatilized Solids	
	Total Solids g	Volatile Solids g	Total Carbon g	Total Solids g	Volatile Solids g	Total Carbon g	Total[a] Solids g	Total[b] Carbon g	Total[c] Solids g	Total[d] Carbon g
WO-1-6	4,000	3,972	1,849	2,703	2,683	1,213	1,302	602	73	34
WO-1-7	4,000	3,972	1,849	2,874	2,854	1,352	967	447	108	50
WO-1-4	4,000	3,972	1,849	2,161	1,977	1,009	1,516	701	302	139
WO-1-5	4,000	3,972	1,849	2,766	2,749	1,295	766	354	434	200
WO-1-1	4,000	3,972	1,849	1,856	1,822	920	1,387	641	622	288
WO-1-2	4,005	3,976	1,852	1,428	1,403	708	2,012	930	463	214
WO-1-3	4,001	3,973	1,850	2,002	1,977	1,058	1,168	540	544	252
WO-1-8	4,000	3,972	1,849	1,879	1,860	1,027	1,201	555	578	267
WO-1-9	4,000	3,972	1,849	1,525	1,510	860	1,456	673	684	316
WO-1-10	4,000	3,972	1,849	2,058	2,039	1,106	854	395	752	348

[a] Total solids weight equivalent calculated from total carbon difference and carbon content of wood

[b] Total carbon weight equivalent calculated from total carbon difference

[c] Total solids weight equivalent calculated from carbon dioxide-carbon monoxide carbon and carbon content of wood

[d] Total carbon weight equivalent calculated from carbon dioxide-carbon monoxide carbon

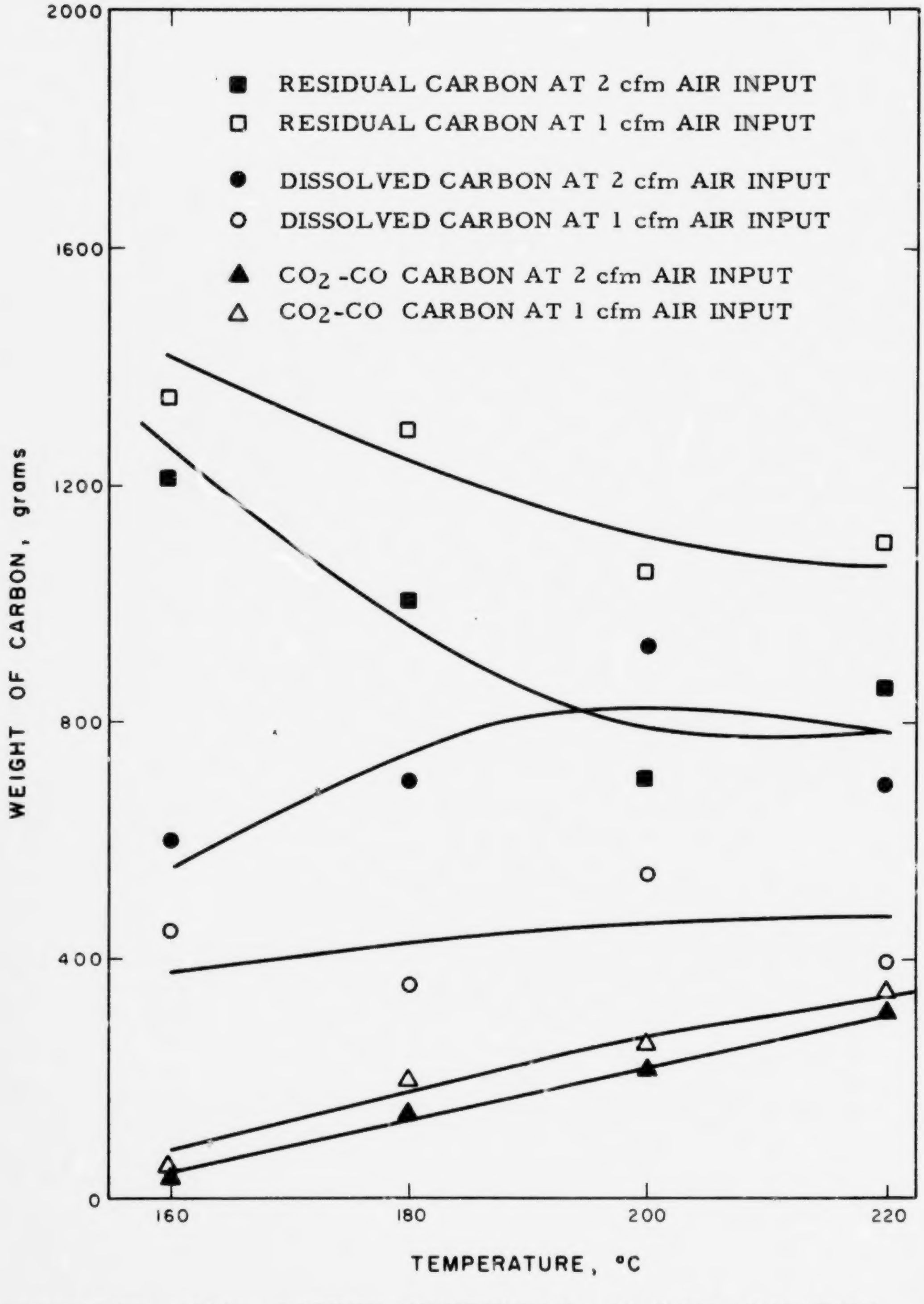

FIGURE 29. TOTAL CARBON DISTRIBUTION IN WET OXIDATION REACTIONS OF WHITE FIR WOOD AS A FUNCTION OF TEMPERATURE AND AIR INPUT

TABLE 43

OXYGEN CONSUMPTION AND CARBON DIOXIDE-CARBON MONOXIDE FORMATION IN WET OXIDATION REACTIONS OF WHITE FIR WOOD[a]

Reaction Number	Gas Consumption					Gas Formation					
	Air g	O_2 Add. g	O_2 Con. g	$\frac{O_2 \text{ Con.}}{O_2 \text{ Add.}}$ %	O_2 Con./100 g Sol. Carbon g	CO_2 g	CO g	$\frac{CO_2}{O_2 \text{ Con.}}$ g/100 g	$\frac{CO}{O_2 \text{ Con.}}$ g/100 g	CO_2/100 g Sol. Carbon g	CO/100 g Sol. Carbon g
WO-1-6	8,077	2,053	2,009	98	316	121	0	6	0.0	19	0.0
WO-1-7	4,409	1,069	990	93	199	177	3	18	0.3	36	0.6
WO-1-4	8,832	2,259	2,166	96	258	466	27	22	1.2	55	3.3
WO-1-5	4,420	1,124	1,035	92	188	668	40	65	0.4	121	7.1
WO-1-1	4,740	1,309	1,195	91	129	1,001	27	84	2.3	108	3.6
WO-1-2	9,127	2,313	2,157	93	189	728	35	37	1.6	64	3.0
WO-1-3	6,548	1,665	1,568	94	198	864	30	55	1.9	109	3.8
WO-1-8	6,981	1,752	1,555	89	189	943	43	67	2.8	115	5.2
WO-1-9	7,841	1,990	1,754	87	177	1,089	45	62	2.6	110	4.6
WO-1-10	4,567	1,143	986	86	133	1,160	58	118	5.9	156	7.8

[a] Gas consumption and formation calculated on the time interval starting at 155°C coming to reaction temperature and ending at 155°C coming off temperature

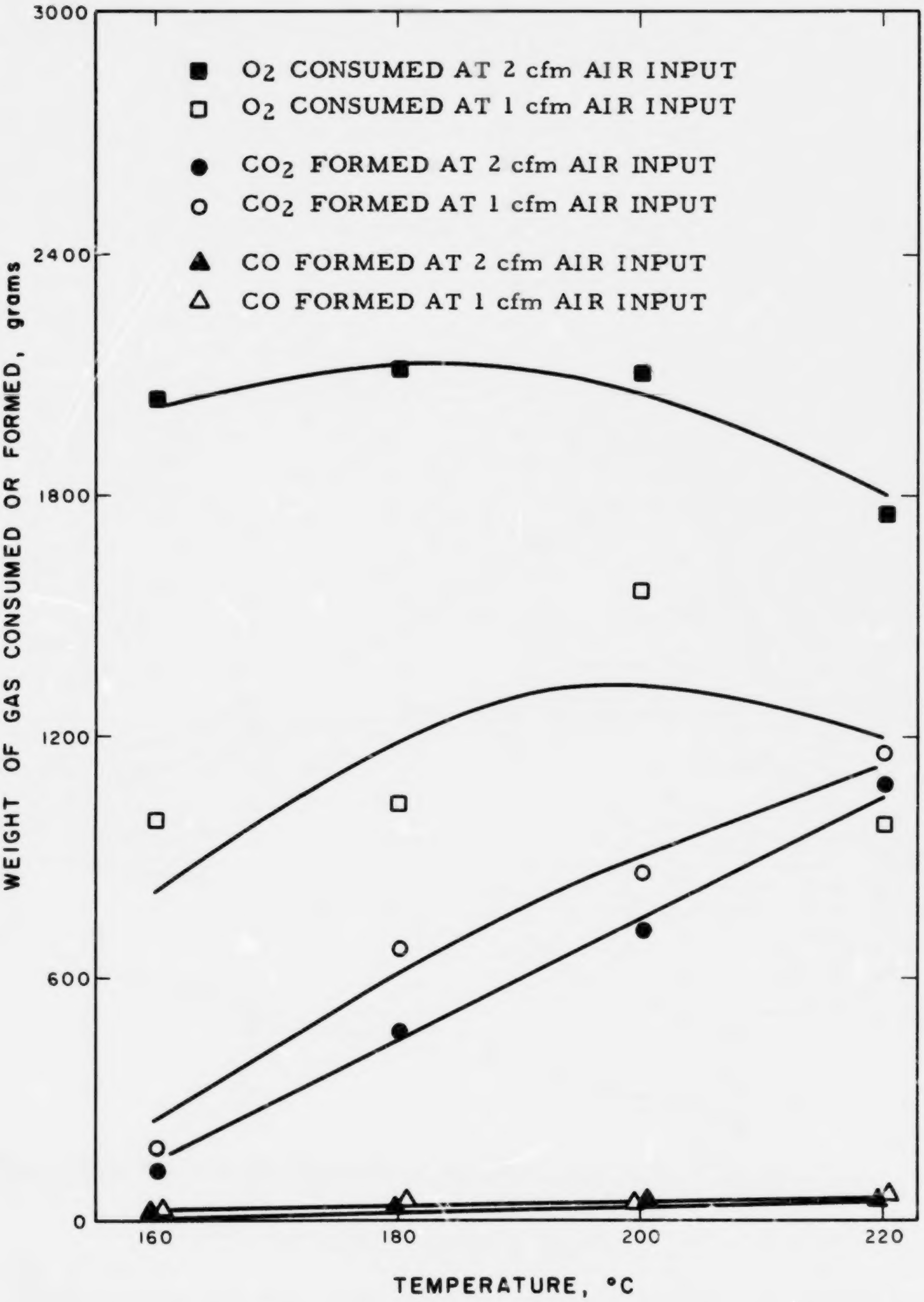

FIGURE 30. OXYGEN CONSUMPTION AND CO_2 - CO FORMATION IN WET OXIDATION REACTIONS OF WHITE FIR WOOD AS FUNCTIONS OF TEMPERATURE AND AIR INPUT

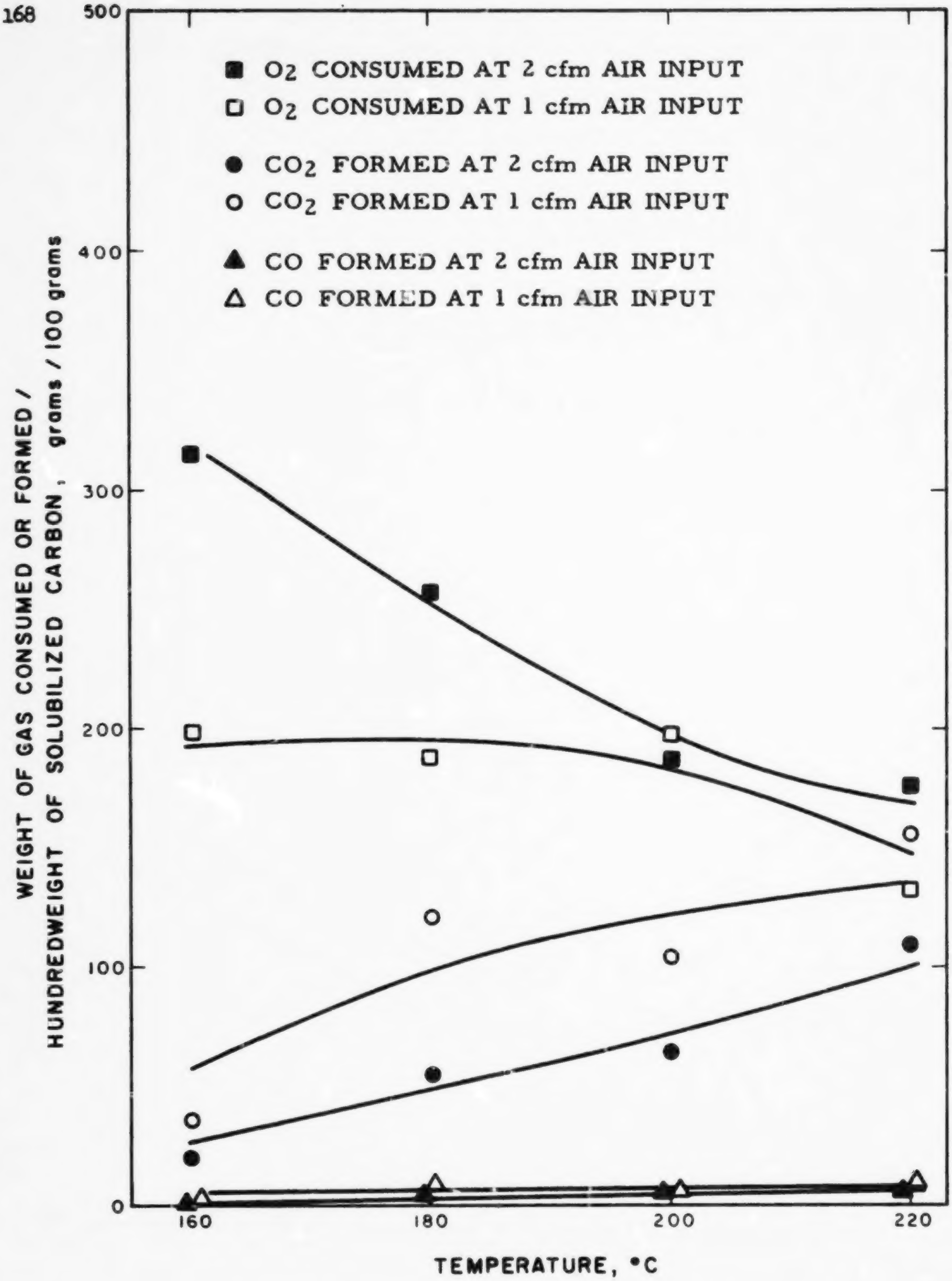

FIGURE 31. OXYGEN CONSUMPTION AND CO_2 - CO FORMATION PER 100 g SOLUBILIZED CARBON IN WET OXIDATION REACTIONS OF WHITE FIR WOOD AS FUNCTIONS OF TEMPERATURE AND AIR INPUT

In addition to some meaningful differences, similar trends were observed in residual, dissolved, and volatilized carbon yields. Carbon contents of the residual solids remained approximately constant (44.9 to 47.0 percent) at 160° to 180°C and then increased with temperature to 56.4 percent at 220°C. This trend indicates that at lower temperatures the reaction is largely hydrolytic with inclusion of oxygen into the residual solids. At higher temperatures, other competing reactions prevail, and oxygen is removed instead of included in the residual solids. These conclusions are corroborated by the data on CO_2-CO formation.

With the temperature at 160°C, despite a total solids reduction of only 30 to 38 percent, the oxygen consumption was as high or higher than at 220°C. This increase in oxygen consumption indicates that large amounts of oxygen were incorporated into the residual solids. Overall oxygen consumption increased with increase in temperature to 200°C, and decreased thereafter, the decrease paralleling the trends for yield of dissolved solids. CO_2-CO formation was relatively insignificant at 160°C, whereas at 220°C it accounted for about one-third to one-half of the total solids reduction. Moreover, CO_2-CO formation was greater at 1 cubic feet per minute air input for every reaction temperature. This latter response indicates that oxygen partial pressure must be a limiting factor in at least one competing reaction which drives the composite oxidation reaction toward greater gas formation, and, more importantly, toward lower levels of solids reduction.

These latter arguments become more explicit when oxygen consumption and CO_2-CO formation are considered on a weight per hundred-weight of solubilized basis.* On this basis, with the air input at 2 cubic feet per minute, oxygen consumption was highest at 160°C, and decreased with increase in temperatures above this point. This negative response is another indication of the dependence of oxygen inclusion on temperature. On the other hand, oxygen consumption at 1 cubic feet per minute remained fairly constant from 160° to 200°C, and decreased with a further increase in temperature. This response illustrates the limiting effect of oxygen partial pressure on total solids reduction. CO_2-CO formation increased with temperature, reaffirming the strong temperature dependence of this gas formation.

As determined in an earlier study [73], the cellulosic fraction of wood is preferentially attacked under acidic conditions such as those generated in Phase I reactions. This preference explains the increase in carbon content of the residual solids with temperature; i.e., the carbon content approaches that of the more oxidation-resistant lignin fraction, about 65 percent, as more and more of the cellulosic fraction is solubilized. In addition, it indicates that the organic chemicals produced in these reactions will be oxidative degradation products of glucose. Although no individual chemical yields have been determined, results [28] of the reaction of molecular oxygen with white fir wood in unbuffered aqueous solution indicate that about 40 percent of the total solids reduction would be recovered as low carbon number, mono- and dibasic aliphatic acids — primarily acetic, formic, oxalic, and glycolic.

In summary, maximum total organic chemical production under the conditions of Phase I wet oxidation reactions would occur at a moderate temperature, 200°C, and an air input rate of 2 cubic feet per minute. Higher temperatures would bring about an increase total solids reduction. However, an increasingly larger amount of the solubilized material would be involved in CO_2-CO formation. At lower air input rates, on the other hand, total solids reduction would decrease and at a given temperature, a proportionately larger amount of the solubilized material would be diverted to CO_2-CO formation.

FUTURE PROSPECTS

The remainder of the current research year will be devoted to the completion of the physical and chemical characterization of Phase I reaction components and to determination of the organic chemical yields. Some modifications of the overall reaction system will also be considered in preparation for Phase II. These will include: a) installation of a more positive stem positioner on the back-pressure control valve to allow for automatic control of total reaction pressure; b) purchase and installation of recorders on the air storage system to provide a continuous record of air consumption; c) addition of a third turbine blade to the agitator to promote greater mixing action in the reactor; d) completion of the air flow indicator-recorder-totalizer system in the instrumentation complex to follow gas consumption-formation relationships more closely; and e) purchase of a rotary belt, vacuum filter to allow faster processing of the reaction effluent.

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*Total carbonless residual carbon.

Phase II should start, as noted earlier, upon completion of Phase I analytical activities. Some process design related to Phase III will be considered during the current research year. Patent potential, where applicable, will also be investigated.

X. INCINERATION – PYROLYSIS

INTRODUCTION

The generalized approach to pyrolysis studies of organic solid wastes was presented in the First Annual Report [1]. The flow of residue, including separation of noncombustible material, preliminary water removal if necessary or advantageous, and pyrolysis into charcoal, liquids, gas, and ash was indicated. In the original study and literature review, pyrolysis at relatively low temperatures, 400° to 600°C, was considered. During the past year, careful consideration has been given to work in progress at the University of California primarily concerned with recovery of heat and inorganic chemicals from kraft black liquor by pyrolysis. A secondary consideration in this work has been the recovery of organic chemicals of commercial value. Cursory work under the black liquor recovery project confirmed the prediction that solid wastes could be handled using the system envisaged, although certain equipment adaptations would be required. Since the black liquor recovery studies had progressed through batch and steady-state pyrolysis stages in the laboratory to a point at which a demonstration pyrolysis-combustion unit could be designed, and since it was apparent that with a minimum of adaptation such a unit could be used in solid wastes disposal, it was considered advisable to combine resources and efforts in the construction of a demonstration unit, taking advantage of the advances that had been made in the technology of the ongoing black liquor pyrolysis study.

Rationale

The pyrolysis of organic material to combustible gas, vapors which can be condensed to aqueous and organic liquid phases, and to carbonaceous residue including inorganic ash, is an old art. Some problems associated with this art have been the production of liquid organic products and carbonaceous residue, and the disposal problems associated with these if their commercial utilization was not possible. Clearly the production of similar products in the pyrolysis of kraft black liquor would also constitute problems; hence, the technique of pyrolysis had to be designed specifically to find solutions to these problems. A further problem in the pyrolysis of kraft black liquor was the production of malodorous sulfur-containing compounds. This, in fact, is the major problem associated with recovery of kraft black liquor as practiced today in over 100 commercial kraft pulping installations in the United States. The original work directed toward black liquor pyrolysis had as its primary objective the solution to this odor problem and simultaneous recovery of heating values and inorganic chemicals.

It has been found that as temperature was increased from a range of 400–800°C to 900–1200°C, many advantages were gained in the solution of the problems presented in the pyrolysis of kraft black liquor [74-78]. These same advantages can be realized in the pyrolysis of solid wastes. For example: the equilibrium constant, $k = [H_2][CO]/[H_2O]$, of the critical reaction which converts solid carbon to combustible gases,

$$C(s) + H_2O(g) \rightleftharpoons CO(g) + H_2(g) \quad ,$$

is approximately 1 at 600°C and increases to about 100 at 1000°C; the more complex organic products formed in the lower temperature range undergo further degradation by various reactions taking place under the more severe pyrolytic conditions to give simple gaseous products with high fuel value. The residual ash, essentially free of carbon, can be processed to recover inorganic chemicals of value, otherwise processed for products of value or, as a last resort, disposed of as solid fill having greatly reduced volume.

Since the work on the pyrolysis of solid wastes would be greatly accelerated by taking advantage of the substantial background accumulated in the study on the pyrolysis of kraft black liquor, the resources of the two projects, viz., Comprehensive Studies of Solids Wastes Management and the Recovery of Kraft Black Liquor, have been coordinated in the design of the demonstration unit. The composition of "typical" solid wastes and kraft black liquor, considered on a gross basis are similar in many respects. This is to be expected since each feed material is essentially derived from vegetable material; i.e., lignocellulose or a fraction thereof. However the nature of the solid wastes feed may differ somewhat because of the admixture of proteinaceous and synthetic (especially polymeric) materials. Because of the differences in the physical states of the two feed materials, different systems must be used for the introduction of the feed. The design or configuration of the pyrolysis units and mode of operation, however, should be similar. Removal of pyrolysis residue may be similar or may again need modification depending upon the feed material and conditions of operation. Accordingly, while the major design is similar for the two feeds, certain aspects involved in materials handling are different and will call for specific attention. This attention is being given in the appropriate project; whereas, design considerations common to both projects are being coordinated as indicated. Clearly, operation of the demonstration unit will necessarily have to be carried out using feed material appropriate to the specific study. However, analytical techniques and equipment, and operating personnel can be common to the two projects and information gained in one study can clearly be used advantageously in the other, an attribute even now realized as noted.

Objectives

The long-term objectives of this research are the conversion of organic matter to 1) usable energy, and 2) commercially valuable products, with no residue or a very minimal amount of residue, drastically reduced in volume, for ultimate disposal, and with no or minimal introduction of pollutants to air or water resulting from such processing. The immediate objective of this research has been the participation in the design and the construction of a demonstration pyrolysis-combustion unit in which the necessary research and developmental work can be conducted to demonstrate technical and economic feasibility in the utilization and/or disposal of solid organic wastes or residues.

BASIC DEMONSTRATION UNIT DESIGN

Pyrolysis as developed in the laboratory indicated that the highest practical temperature should be attained to insure highest rates of favorable reactions, maximum production of simplest fuels, minimum production of complex higher-boiling products, and, when sulfur is present, maximum retention of sulfur as sodium sulfide and minimum production of complex organic sulfur-containing products. It has been demonstrated that pyrolysis above 750°C is limited by materials that may be used in fabrication of equipment, yet laboratory studies indicated that a temperature of approximately 1000°C should be attained if possible. To realize temperatures in the range desired it was decided early in the study that a two-stage pyrolysis demonstration unit should be designed and operated to obtain the pertinent information needed to demonstrate technical and economic feasibility of the process.

It was decided that the first stage of pyrolysis should be carried out at a temperature such that indirect heating by transfer through a metal wall could be effected. Since free water in the feed material was to be evaporated in this stage and pyrolysis was to be carried to an optimum point, one that will be established by the operation of the demonstration unit, this unit had to be designed with the maximum possible flexibility. In general, the first stage has been visualized either as a spray-drying pyrolysis or as a fluidized bed-type operation. It was anticipated that a maximum wall temperature not to exceed 750°C, and probably in the range of 500° to 700°C, should be achieved.

In the second stage of pyrolysis it was decided that temperature should be increased to a maximum. Again applying the guideline that the demonstration unit should provide the greatest practical flexibility, it was decided to design for an operating temperature as high as 1200°C in this unit. This specification clearly eliminated the use of metal and required the use of special ceramic materials. In the case of pyrolysis of kraft black liquor it would then be possible to withdraw the ash, consisting of sodium carbonate plus sodium sulfide, as a smelt which becomes molten at approximately 850°C. It was planned to complete the conversion of organic matter to gaseous products in this unit, thereby simplifying withdrawal of products as much as possible.

To attain the temperature specified it was not feasible to use indirect heating because of the low thermal conductivity of ceramic materials that could be used. Instead it was planned to achieve the desired maximum and controlled temperature by metering sufficient air into the zone at which first stage pyrolysis products are introduced to effect exothermic reactions at a level that will give the requisite heat. Beyond this zone it was anticipated that the oxygen will be exhausted and the conditions in the unit will again become reductive by completion of pyrolysis reactions, including the formation of hydrogen and carbon monoxide by reaction of residual carbon with water vapor. It was also anticipated that any sulfur oxides formed in this transient oxidizing zone will be absorbed in the strongly alkaline environment and subsequently reduced to sulfide. Further, a more prolonged contact of pyrolysis gas with molten smelt and with "fume" or sodium oxide in the gaseous phase should effect a more complete reaction with hydrogen sulfide to form sodium sulfide. Maximum retention of sulfur as sodium sulfide, which would finally issue from this unit in smelt, will be highly desirable when this unit is operated to give results equivalent to recovery obtained in a conventional kraft process.

Pyrolysis gases, issuing from the second stage pyrolysis unit if essentially free of sulfur, could be used without cooling in a stoichiometric combustion zone to produce heat. Gases containing an amount of sulfur products that would constitute a nuisance or, due to sulfur loss from the processing chemical as in kraft recovery, an economic liability, would first be subjected to absorption. Absorption will be carried out at process temperature without cooling, or with minimum cooling, to give an optimum temperature. The absorbent used will be calcium carbonate, calcium oxide, sodium carbonate, or other suitable material. If storage of the final pyrolysis gas is necessary or desirable or if the gas should be transported a distance before being used in combustion to produce heat, it might become desirable to utilize a portion of the sensible heat in the gas by appropriate heat exchange. A schematic design of the demonstration unit is presented in Figure 32.

An alternative type of processing of pyrolysis products that has been visualized throughout this work, which is as much a possibility in using solid wastes as it is in using kraft black liquor as the raw material feed, would involve the recovery of organic chemicals from the pyrolysis streams. This could be done after the first stage or the second stage in the processing described, or if desirable, intermediate stages of pyrolysis might be used specifically to maximize the production of such products.

PROGRESS DURING PAST YEAR

Substantial progress, made during the research period has involved refinement of the demonstration unit design, theoretical calculations concerning various aspects of operating such a unit, and initial construction of the demonstration unit.

In design aspects, extensive consultation with representatives of a ceramic materials supplier led to the selection of ceramics that would be used throughout the system. The most difficult problem of corrosion, that anticipated in the second stage reactor, can only be resolved by actual operation of the unit. A basic castable refractory was finally selected based on the recommendation that it probably would be the most resistant to corrosion under the expected conditions of operation. With similar study of the problem of corrosion in the first stage reactor, it was concluded

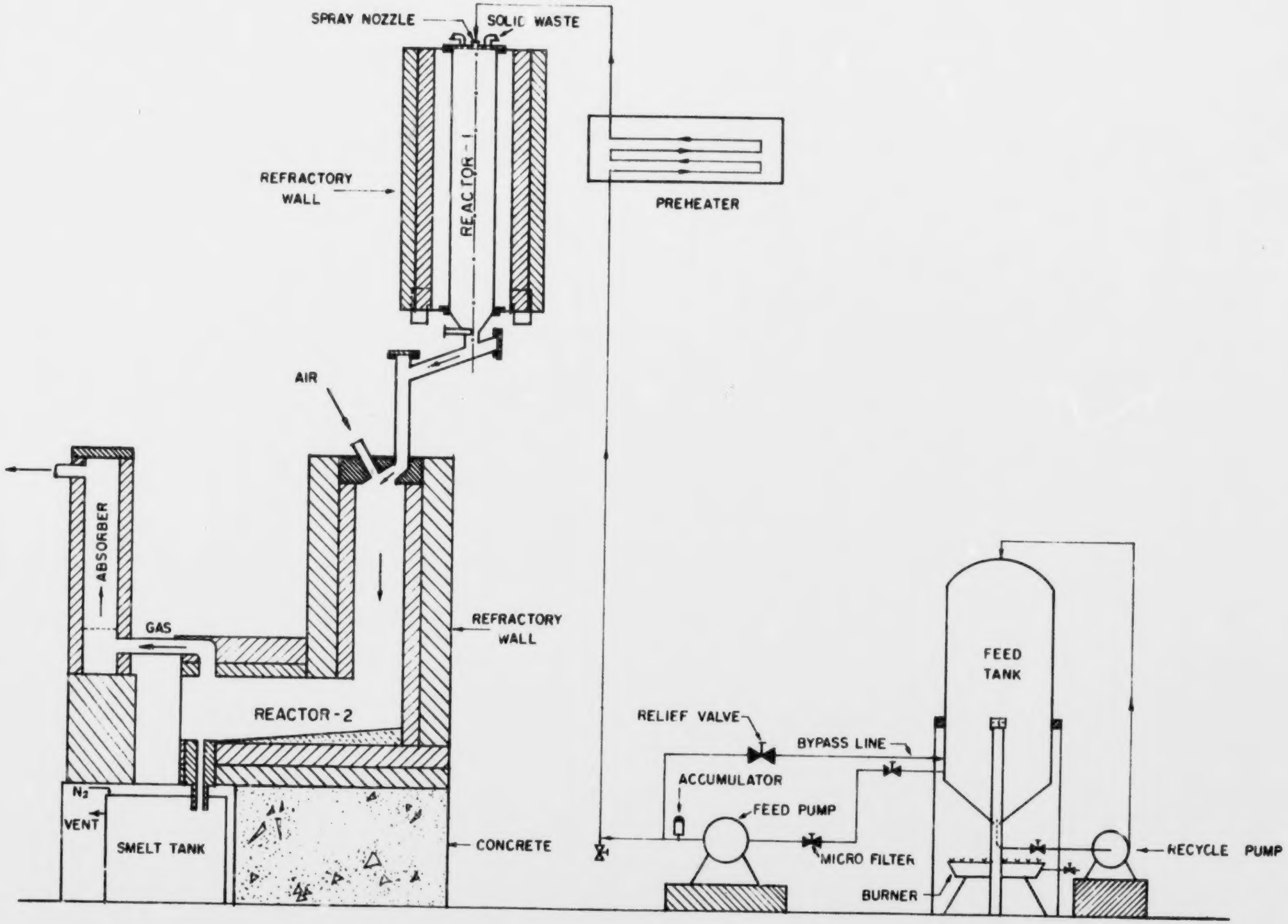
SPRAY NOZZLE
SOLID WASTE
REFRACTORY WALL
REACTOR - 1
PREHEATER
AIR
PYROLYSIS GAS
ABSORBER
GAS
REFRACTORY WALL
REACTOR - 2
N_2
VENT
SMELT TANK
CONCRETE
RELIEF VALVE
BYPASS LINE
ACCUMULATOR
FEED PUMP
MICRO FILTER
FEED TANK
BURNER
RECYCLE PUMP

FIGURE 32 . SCHEMATIC OF A TWO-STAGE PYROLYSIS-COMBUSTION UNIT that operating temperature must be limited to the range indicated even with the careful selection of a type of metal to be used. The metal finally selected, stainless steel type PH 15-7MO was considered superior in resistance to high temperature corrosion to type 316 or 321 because of its higher transition temperature. Stainless steels in the 400 series, which have a martensitic structure, were considered unsuitable because of substantial difficulties encountered in using them to fabricate large pieces of equipment. Other metals described in the literature were special types that are very difficult to obtain.

Consultations were held with a representative of a heat consulting firm in the design of the gas fired furnaces that are to be used in heating the first and second stage pyrolysis units and the liquor preheaters, and in combustion of the final pyrolysis gases. Safety of operation was stressed in all considerations. Design of units was carefully studied and equipment for control and heating was specifically recommended by the firm for each particular use.

Calculations [79] of heat and materials balances for the first and second stages of pyrolysis made with the use of existing data and necessary assumptions have provided theoretical evidence which demonstrates that heat recovery should be equal to or better than that which can be achieved in modern kraft recovery furnace practice. Retention time and heat transfer to solid wastes particulate matter when using the first stage as a partially filled batch reactor have been estimated. Using essentially the same information, a calculation was made of the heat transfer to a sewage sludge feed, assuming operation of the first-stage pyrolysis unit under two modes of operation. It was found that in a fluidized-bed mode of operation, heat transfer would be many times more efficient than in a heated-wall, atomized-spray reactor.

Construction of the demonstration unit was initiated as an outdoor structure on a concrete pad. A two-story, metal frame was erected on the pad, the first-stage pyrolysis chamber was fabricated with 4-in. ducting to transfer pyrolysis products to the second stage; construction of the second-stage pyrolysis unit was initiated, an 8 ft by 12 ft control building was put in place, and most of the gas burning and control equipment was procured.

FUTURE PROSPECTS

Research activities during the remainder of the current fiscal year may be placed in three categories. The first phase will be devoted to the completion of the construction of the demonstration unit. Plans for this with respect to kraft black liquor pyrolysis are essentially complete and most equipment and supplies are on hand or will be ordered very soon. Adaptation of a solids wastes feed system and a solid ash removal system is yet to be designed for the first- and second-stage pyrolysis units, respectively. Otherwise, construction of the demonstration unit for operations involving solid wastes is at a point of completion similar to that for kraft liquor.

The second phase of research activities will be concerned with placing the demonstration unit into operation. This will be accomplished initially using kraft black liquor. After completion of the necessary modifications, studies involving solid wastes will be undertaken.

The third phase of the research activities will be concerned with analytical activities. It is intended to sample pyrolysis products after each major step in processing. This will include gases, vapors condensed to liquids, and solids. Many of the analytical techniques have been developed for this work but it is anticipated that more work will be required. Very thorough attention will have to be given, when the unit is placed in operation, to the collection of appropriate samples and the carrying on of meaningful and significant analyses.

XI. BIOLOGICAL FRACTIONATION OF ORGANIC WASTES

INTRODUCTION

One method for recycling organic materials from the solid wastes stream is biological fractionation. The contribution of a process of this nature to wastes management rests in the fact that through it by-products of elevated economic value and a usable residue are produced. Inasmuch as it is unlikely that a single process could be developed to treat the wide spectrum of organic materials found in solid wastes, obviously for a biological fractionation process to make a significant contribution to the solution of the solid wastes problem, it should involve the use of that component of the wastes stream which is in greatest abundance in that stream. The material which immediately comes to mind is cellulose.

Rationale

The biological aspects of a process based on the microbial decomposition of cellulose should pose no problem, since in nature cellulose decomposing microorganisms are the principal agents in nature responsible for the degradation and recycling of the cellulose in woody and herbaceous plants. They perform the very important ecological function of converting the water-insoluble cellulose to readily utilizable nutritional forms of carbon. Moreover, according to the literature there is an abundance of microorganisms capable of converting cellulose to a variety of useful products such as organic acids (acetic, bactic, formic, and propionic), ethanol, glucose, and single-cell protein.

These considerations, namely the fact that cellulose constitutes the largest fraction of the organic wastes, that cellulose decomposers are abundant in nature, and that biological decomposition can result in the production of desirable by-products as well as microbial protein, led the research team concerned with biological fractionation to concentrate its attention on the development of a process based on the decomposition of cellulose. In doing this, they are directing their research to the adaptation of the natural microbial process to an economically feasible industrial means of converting the cellulosic fraction of the wastes to useful materials. The stategy of the team is to determine a process which will effect a rapid and economic conversion of the cellulose and which will produce readily recoverable products of value and which are in demand.

A biological process which performs an economical conversion of cellulose is potentially valuable in modern wastes treatment, since cellulose in the form of wastepaper constitutes approximately 50 percent of domestic solid wastes. The conversion of cellulose and subsequent recovery of products can be done in a manner that meets two important criteria for good wastes treatment: 1) the wastes undergoing treatment do not reappear in other forms of wastes (air, water, or terrestrial pollution); and 2) useful substances are produced, i.e., the converted wastes are recycled as resources.

The fact that microbial decomposition of cellulose is a natural ecological process lends a good prospect of success to any technique involving the use of microbes to recycle the carbon in wastes. A major part of the problem of wastes disposal stems from the fact that man interferes with ecological equilibrium by generating more wastes than can be decomposed by natural means. Since man is interfering with the equilibrium of nature, it seems logical that a powerful means of combating the wastes problem would be to attempt to restore the equilibrium by an augmentation of the normal ecological process, microbial decomposition.

Very little work has been done on the systematic application of microbial decomposition in wastes treatment. The general subject of the microbial decomposition of cellulose has been well summarized by Siu [22] and Gascoigne [80]. Siu's work is concerned mainly with the subject of the undesirable attack of cellulose decomposers on textiles. Gascoigne devoted his attention to the in vitro enzymatic hydrolysis of cellulose and related materials. Neigher of the two researchers was concerned with the use of microorganisms in solid wastes treatment. Several workers [81-83] have investigated the use of thermophilic, anaerobic, mixed bacterial cultures to produce organic acids and ethanol from various cellulosic wastes substrates. Results have differed greatly, probably due mainly to differences in the characteristics of the mixed cultures. Enebo [84] was the first worker to do a detailed analysis of the characteristics of a mixed culture of thermophilic cellulolytic bacteria; he demonstrated the importance of symbiosis in the culture which he studied. Various pilot plants have been built in attempts to employ thermophilic bacteria in a process to produce organic acids and ethanol from cellulose wastes. There were abandoned after a short while because the thermophilic systems proved to be noncompetitive with existing commercial processes for ethanol and organic acid production.

The two products of microbial cellulose decomposition which are likely to be increasingly valuable in the future are glucose and single-cell protein. A process designed to consume cellulosic wastes and produce both edible protein and carbohydrate sources seems certain to become increasingly feasible as the wastes accumulate and the protein and carbohydrate demand grows with the population. If this be true, the most promising field for research would be in the application of microbial cellulose decomposition to the production of protein and carbohydrates. Therefore, it is to that end that this phase of research of the biological fractionation team is directed.

Objectives

The general objective of this phase of the overall research is the development of an economically feasible process for the decomposition of the cellulosic fraction of solid wastes by microorganisms. An important aspect of this process will be the recovery of cellulose decomposition products so that they may be recycled into the economy as resources.

The immediate and specific aims of the research are:

1. The selection of those microorganisms most suitable for the process.
2. The specific determination of nutrient requirements, growth rates, and enzyme activities of the selected microorganisms.
3. Analysis of the cellulose decomposition products of the selected microbes.
4. The determination of methods of product recovery and utilization with particular consideration being given to the recovery of cell material as a protein source and glucose as an energy and carbon source.
5. The establishment of the optimum overall scheme for the processing of the cellulose fraction of solid wastes by suitable microorganisms.

THE INVESTIGATION

Organisms

A major reconsideration of the types of microorganisms to be used in the research was made since the First Progress Report. The intent to use the rumen bacteria and the mixed culture of clostridia and related species (isolated by Enebo [84]) has been given up, because the probability is strong that the complex and therefore expensive growth media requirements would make a process based on such organisms economically unfeasible. Selected to replace them are the aerobic bacterium *Sporocytophaga myxococcoides* and the fungus *Myrothecium verrucaria*. *S. myxococcoides* is a soil inhabiting, aerobic bacterium which plays a very important role in the decomposition of cellulose in soil. Its optimum growth temperature is about 30°C. Advantageous characteristics of the organism are its ability to decompose cellulose rapidly and its simple growth requirements. Siu [22] reports shaker flask experiments with *S. myxococcoides* in which 98 percent of the cellulose was decomposed in 6 days. Another characteristic of this bacterium is the limitation of its metabolic products to cell material, carbon dioxide, and only traces of other materials. The failure to synthesize in appreciable amounts metabolic products such as organic acids may be a main reason for the organism's ability to decompose cellulose so rapidly, since such products typically inhibit growth and enzyme activity.

Myrothecium verrucaria is probably the most active of the cellulolytic *Fungi imperfecti*. It grows well on a simple mineral medium at an optimum temperature of about 30°C. Siu [22] reports shaker flask experiments in which 80 percent of the cellulose was decomposed in 14 days. This decomposition rate is much lower than that accomplished by *S. myxococcoides*. However, the cell-freeze enzyme extract of *M. verrucaria* has a much higher cellulolytic activity than that of *S. myxococcoides*. Reese and Levinson [85] report a cellulolytic activity of 1.01 for *M. verrucaria* and 0.40 for *S. myxococcoides* (activity expressed as mg glucose per mℓ per hours).

Description of the Process

A tentative processing scheme for the production of single-cell protein and glucose from cellulosic wastes material by microbial action is shown in Figure 33. The method is based on presently published information on typical fungi and aerobic bacteria such as *S. myxococcoides* and *M. verrucaria*. Specific details on process conditions and equipment remain to be established in the course of this project. The processing scheme presented below is intended to serve as a basis for obtaining a preliminary perspective on the feasibility of this approach.

In the process, ground cellulosic wastes are mixed with water and necessary mineral salts in a medium preparation vessel. The fermentation medium is then passed through a sterilizing unit to destroy contaminating microorganisms. At present, it is not clear as to whether or not the sterilization step will be necessary, inasmuch as contaminating microbes may be sufficiently limited by the manipulation of operating conditions such as pH, temperature, nutrients, and concentration of glucose in the fermenter. The cellulose suspension medium then enters a fermenter where the growth of the microorganisms take place, the cellulose is broken down, and cell material, carbon dioxide, and the extracellular cellulolytic enzyme, cellulase, are produced. In order to permit a high rate of cellulose decomposition and a heavy concentration of cellulase, the cell material is separated from the effluent and recycled into the fermenter. A bleed is taken off of the recycle stream to harvest the cell material and prevent too high a buildup of cell population.

The liquid effluent from the reactor is then fed into a hydrolysis vessel in which it comes in contact with a cellulose suspension. The cellulase present in the liquid effluent from the fermenter serves to hydrolyze the cellulose to glucose. Cell growth must be prevented during the hydrolysis step in order to prevent the loss of glucose. This is accomplished by the addition of an antiseptic such as toluene to the hydrolysis medium. The exit stream from the hydrolysis vessel enters a separator in which the cellulose is separated from the liquid and recycled into the hydrolysis vessel. The liquid effluent is sent to an evaporator which concentrates the solution to 80 percent glucose. Successive crystallization, washing, and drying are employed as required to obtain a sufficiently pure glucose product.

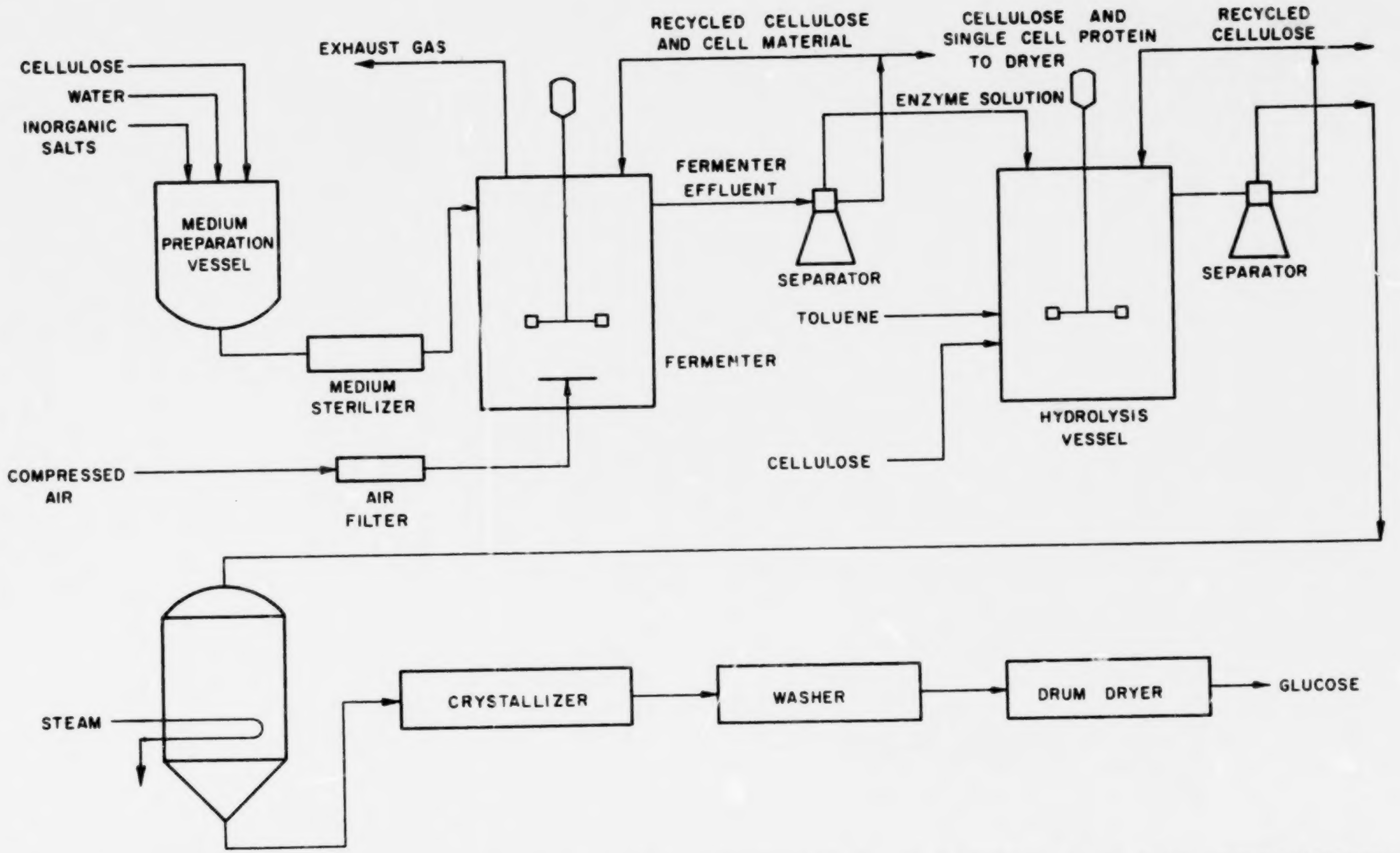
CELLULOSE
WATER
INORGANIC SALTS
MEDIUM PREPARATION VESSEL
MEDIUM STERILIZER
COMPRESSED AIR
AIR FILTER
EXHAUST GAS
FERMENTER
RECYCLED CELLULOSE AND CELL MATERIAL
FERMENTER EFFLUENT
SEPARATOR
CELLULOSE AND SINGLE CELL PROTEIN TO DRYER
ENZYME SOLUTION
TOLUENE
CELLULOSE
HYDROLYSIS VESSEL
RECYCLED CELLULOSE
SEPARATOR
STEAM
CRYSTALLIZER
WASHER
DRUM DRYER
GLUCOSE

FIGURE 33. SCHEMATIC REPRESENTATION OF A CONTINUOUS PROCESS FOR THE PRODUCTION OF PROTEIN AND CARBOHYDRATE FROM CELLULOSIC WASTE MATERIAL

Development of Equipment

During the period covered by this report, a major part of the work consisted of designing and constructing a system involving three culture vessels. A diagram of the system is presented in Figure 34. Photographs of the apparatus are shown in Figures 35 and 36. The units may be operated independently or in series as required.

The central part of each of the three units is a 14-liter culture vessel made of pyrex glass and equipped with a stainless steel head containing the necessary inlets, outlets, ports, and control probes for the operation of the system. Temperature control is accomplished by a proportional temperature controller which receives a signal from a thermistor located in a stainless steel well submerged in the culture liquid. When the temperature of the culture broth falls below the desired temperature, the controller activates a heating element in a water bath which is continuously circulated through hollow baffles submerged in the culture vessel. The temperature of each culture vessel is continuously displayed on a chart recorder. Very accurate temperature regulation has been achieved by this control system.

The hydrogen ion concentration (pH) is continuously controlled by an industrial type pH analyzer. The pH of each culture vessel is measured by steam-sterilizable pH and reference electrodes submerged in each vessel. When the pH deviates from the desired level, a peristaltic metering pump is activated which feeds either acid or base into the culture medium until the proper pH level is restored. The pH of each culture vessel is continuously recorded on a multipoint chart recorder.

Provision is made for the control of foam which is frequently a problem during the growth of aerobic organisms. An antifoam probe is inserted in each culture vessel. It sends out a signal to a control unit when excessive foam develops above the culture broth. The signal activates a peristaltic metering pump which feeds an antifoam agent into the culture until the foam is reduced or eliminated.

Each culture vessel is equipped with a level control unit which is used to maintain the culture broth at a constant volume during continuous runs. When the liquid level rises, a level probe inserted into the vessel sends out a signal which causes the level control unit to open a solenoid valve on an exit line leading from the fermenter. When the level is reduced to normal, the valve closes.

Agitation of the culture broth is accomplished by a stirring shaft driven by a 1/3 hp DC motor. The rotational velocity of the motor shaft is held constant by a motor control unit, and the rpm of the shaft is measured by a tachometer which sends a signal to a recorder which in turn registers the speed.

Aeration is provided by a sparger located at the bottom of each culture vessel. Air is provided by compressed air tanks, and flow rate is controlled by a pressure regulator and adjustable flowmeter. Sterilization of the incoming air is achieved by passing it through an air filter containing glass wool. Humidification of the air is accomplished by sparging the incoming air in water after it passes through the filter. Humidification is needed for reducing evaporation of water in the fermenter as the air is passed through it.

Experimental Work

The experimental work being carried out in this phase of the process technology is the investigation of variables involved in the proposed process and the optimization of the process. The specific areas of experimental study are as follows.

Optimization of Enzyme Production. The key to the entire process of microbial cellulose decomposition is the production of the extracellular enzyme cellulase by cellulolytic microbes. The enzyme is responsible for the hydrolysis of the water insoluble cellulose to glucose – thereby making glucose available for cell maintenance and growth. Very little work has been done on the investigation of the relationship

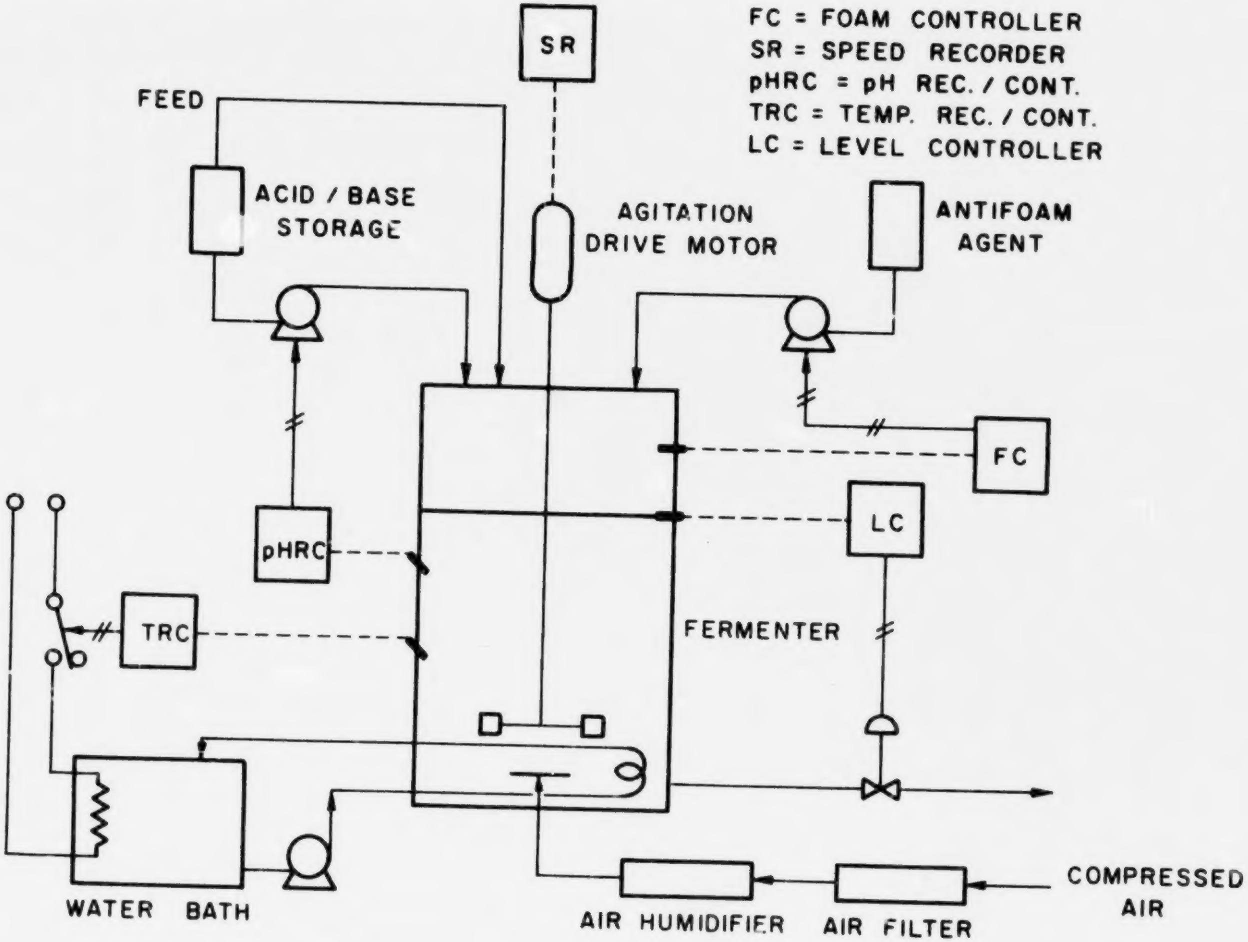
FC = FOAM CONTROLLER
SR = SPEED RECORDER
pHRC = pH REC. / CONT.
TRC = TEMP. REC. / CONT.
LC = LEVEL CONTROLLER
SR
FEED
ACID / BASE STORAGE
AGITATION DRIVE MOTOR
ANTIFOAM AGENT
FC
LC
pHRC
TRC
FERMENTER
WATER BATH
AIR HUMIDIFIER
AIR FILTER
COMPRESSED AIR

FIGURE 34. SCHEMATIC DIAGRAM OF FERMENTER AND CONTROL SYSTEM

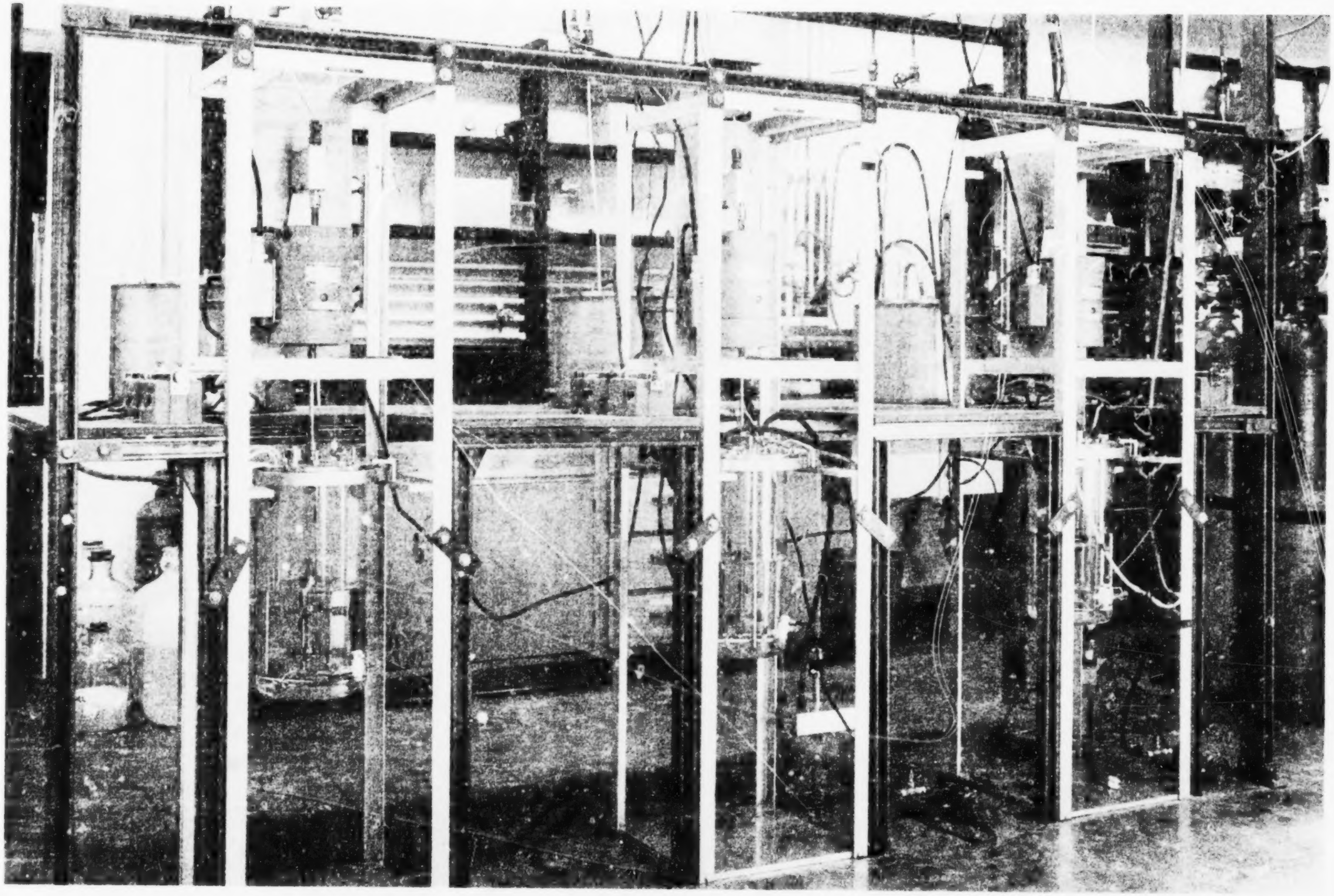

FIGURE 35. SYSTEM OF THREE CULTURE VESSELS

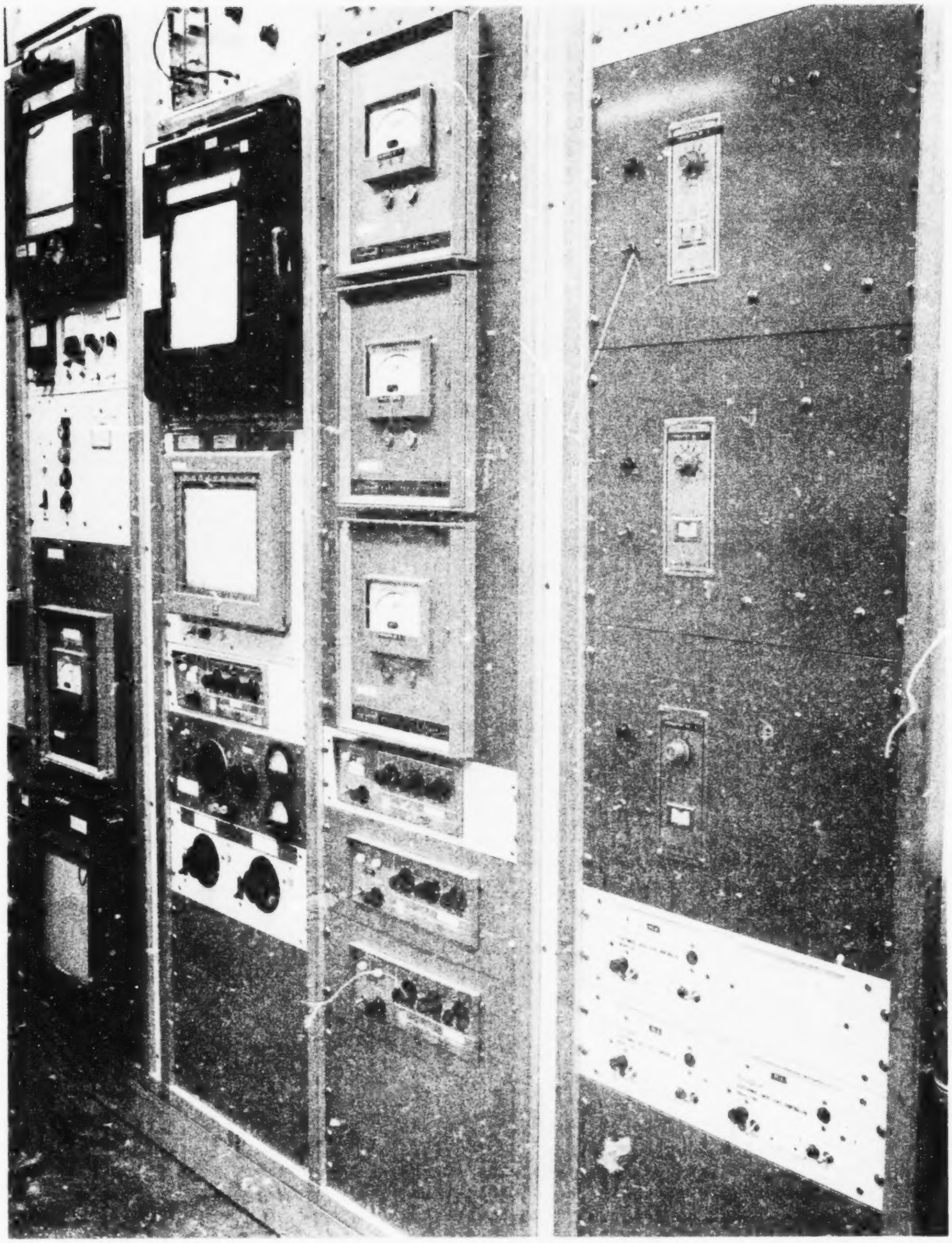

FIGURE 36. CONTROL PANEL FOR CULTURE EQUIPMENT

between environmental factors and enzyme production. As yet it is not clear as to whether cellulase is a constitutive (present regardless of specific culture medium) or an inducible (produced only when a particular substrate is present) enzyme. A proper understanding of the constitutive or inducible nature of the cellulose produced by a specific microorganism is necessary in the optimization of enzyme production. Factors such as these are to be tested in an attempt to produce much higher enzyme concentrations than possible under ordinary conditions.

Maintenance of Enzyme Activity. It has been consistently observed that the activity of the cellulase enzyme decreases greatly as it hydrolyzes cellulose. The probable cause for this is an inhibitory mechanism built into the protein structure of the enzyme. Probably molecules of decomposition products become attached to sites on the enzyme molecule and thereby deactivate it. To circumvent this difficulty, it might prove practical to remove the hydrolysis products as soon as they are formed, and thus prevent or delay the inactivation of the cellulose.

Recovery of Enzyme. If it can be shown that there is no intrinsic property of the cellulase enzyme system which leads to an irreversible deactivation, then it would be advantageous to recover and recycle the enzyme as it is produced. A possible means of selectively retaining the enzyme during the separation of the glucose after the hydrolysis would be the use of a dialysis membrane through which glucose would pass, but not the larger enzyme molecules. Experimentation will be carried out to ascertain the effectiveness and feasibility of the use of such a membrane to selectively retain the cellulose. Other possible means of achieving the same end, such as molecular sieve operations, also will be investigated.

In case enzyme recovery is not economically feasible the residual enzyme would be removed in the glucose recovery steps.

Dense Culture Technique for Rapid Decomposition. One of the difficulties inherent in the microbial cellulose decomposition process is the relatively slow (compared to soluble substrates) rates of cellulose uptake by the growing cells. Obviously, any means by which this process could be enhanced would be beneficial. It has been shown that it is possible to substantially increase the productivity per unit fermenter volume by removing broth continuously from a culture while retaining most of the cells [86]. This is known as the dense culture technique.

In the proposed process, the cell material leaving the fermenter is separated from the liquid effluent and returned to the fermenter except for the cells suspended in the bleed stream. By this technique it should be possible to maintain a higher cell concentration than ordinarily would be possible. The maintenance of a dense cell population will result in an increased enzyme production and a subsequent rise in the rate of cellulose decomposition during the fermentation.

SUMMARY

As a result of a literature survey, the aerobic bacterium Sporocytophaga myxococcoides and the fungus Myrothecium verrucaria were selected for research on the basis of their being the most promising of the microorganisms with respect to cellulose decomposition under the conditions to be met in the treatment of solid wastes. Two previously considered mixed bacterial cultures, the rumen bacteria and Enebo's thermophilic anaerobic bacteria, were dropped from further study in favor of the above two organisms.

A bank of three fermenters equipped for automatic control of temperature, pH, liquid level, and foam was constructed in the laboratory. This system is described in detail.

A complete processing method is proposed through which cellulose is converted to protein in the form of dried cell material, and to carbohydrate in the form of glucose. This process is described and depicted schematically.

Experimental work directed at investigating the actual feasibility of the proposed process and the possibility of optimization by process modifications is outlined. The outlined work is to be carried out on a laboratory scale with equipment already built. The specific areas of investigation are:

1. Optimization of cellulose production.
2. Maintenance of cellulose activity.
3. Recovery and recycling of cellulose enzyme.
4. Use of dense culture techniques to achieve rapid cellulose decomposition rates.

XII. SUMMARY

INTRODUCTION

Progress is reported for the second year and early months of the third year of a research project entitled "Comprehensive Studies of Solid Wastes Management" being conducted as a multidisciplinary study of the planning, economics, operations research, public health, and technological aspects of regional solid wastes problems.

First attention in the report is directed to changes in the nature of the problem of solid wastes which have occurred since the project was initiated in 1966. At that time, the most urgent aspects of the problem of solid wastes management were the outgrowth of deficiencies in planning, politics, economics, technology, and general public awareness of the environmental threats of solid wastes. Essentially, no plan for land use included the dedication of any land for wastes disposal, and the tendency was to consider land too valuable for such a purpose if it could conceivably be used for any other profitable enterprise. Jurisdicational fragmentation of communities precluded regional solutions to the solid wastes problem, although it had already reached regional proportions. In addition, public concern for refuse disposal was historically oriented to domestic refuse with little sense of public responsibility for industrial, commercial, and agricultural wastes. Technology had not resolved the problems of solid wastes disposal, and even the disposal of domestic wastes was increasingly complicated by an increasing content of plastics and other undegradable materials. A crisis in solid wastes developed as the nation increasingly included esthetics and "quality of life" in its environmental goals.

During the period 1966-68, identifiable changes in the problem are reported, although the real problems of 1966 continued to be generally unresolved. The Solid Wastes Program of HEW developed its research and demonstration grants program; numerous communities took stock of their own solid wastes problems; private enterprise became interested in the question of how it might contribute; and planning agencies became aware of a land-use planning deficiency in relation to solid wastes.

The effect of these changes, however, was more apparent than real. Principally, the new concern of solid wastes—oriented citizens directed against landfills, incinerators, and other wastes-related systems; no new authority accrued to planning agencies; and the imminence of regional jurisdictions tended to polarize local officials and revive latent provincialism. The gross effect as viewed by the authors of the report was to make the land use, and consequently the solid wastes, planning problem more acute in 1968 than in 1966. It is concluded that awareness rather than resolution characterized the changes in 1966 problems during the subsequent two-year period.

Emerging concepts cited in the report include a shift in emphasis from "control of pollutants" in the environment to "quality of the environment" as the conceptual basis for public policy. Thus a resource quality approach opens the way to consideration of the long-range effect of man on the entire ecosystem, and adds to public unwillingness of people to accept refuse disposal as a beneficial use of land. Simultaneously, the pretense persists in the press and in the public mind that such partial solutions to wastes disposal as incineration and composting of the organic fraction of solid wastes is an alternative to landfill. Meanwhile, concepts of "environmental insult" and "land pollution" compound the problem of wastes management.

The report emphasizes that the Number One Problem as viewed by public officials is "finding any location at which to do whatever it is you need to do, whether it be a transfer station, an incinerator, a landfill, a processing plant, or even a transport route."

Program emphasis, it is reported, is heavily oriented to the disposal phases of refuse management, although 80 percent of the cost of management is in the collection phase. The reason cited is this matter of site acquisition. However, the collection system cannot for long be ignored because of its heavy dependence upon labor and the changing cultural patterns which make labor-dependent systems difficult to maintain. A table is presented which compares solid wastes collection systems with other utility and natural systems on a conceptual basis not previously reported in the literature. From it, the unhappy conclusion is reached that the present collection system is destined to fail in the long run, hence unsolved problems in that aspect of solid wastes management must be faced even before the persistent problems of disposal are resolved.

The relation of public health to solid wastes management is considered in some detail because, although it is a rationally inescapable concept that refuse problems involve public health problems, no one has been very successful in attacking this aspect with a team of specialists oriented to environmental health. Three types of problems are identified:

1. Problems which are reasonably well solved, but remain solved only by constant vigilance.
2. Problems which are unsolved, but are incapable of resolution independent of technological, political, and planning problems.
3. Problems which remain either unidentified or unevaluated in relation to other environmental hazards.

RESEARCH ACTIVITIES AND FINDINGS

A summary of the objectives, rationale, and investigative findings of research teams giving special attention to various aspects of the project constitutes the body of the report. For convenience in presenting the findings, separate chapters have been devoted to Planning, Operations Research, Economics, Public Health, and five aspects of Technology.

Planning

Planning, economics, and operations research are closely integrated aspects of the investigation. The planning aspect, however, is particularly concerned with:

1. Development of structural models with which, on the basis of related variables and land-use projections, to predict in detail the solid wastes which will be generated in a community or region.
2. Exploration of the implications of changes in transportation and disposal technologies in solid wastes management and resource use in a community or region.

To approach these objectives, it was necessary to select a study region and therein to explore the relationships between employment, economic status, population density, employment, land use, and similar factors, and the kind, amount, and place of origin of various fractions of the overall solid wastes generated. The nine-county San Francisco Bay Area was selected as an operational region from which to derive the factual basis for a regional solid wastes generation model; and in which to test the validity of the model as a device for estimating future amounts of solid wastes and arriving at solutions to the problem of managing them within the functional boundaries of a region.

Because there does not exist enough specific detailed data on solid wastes to make possible the establishment of a quantitative relationship between sources of wastes and the various activities of man, it is impossible to set up an ideal approach which would permit interpretation of any land-use pattern that might be planned directly in terms of solid wastes which it would generate. A modified approach was therefore utilized in which the needed data on solid wastes generation were developed from source units and wastes multipliers by a regression analysis. This meant that the sources themselves had to be studied in greater detail — an undertaking far more feasible than the more desirable study of wastes quantities within the constraints of time and budget for the project. A considerable portion of the report on the planning aspects is devoted to the development of necessary solid wastes multipliers from population versus total wastes generated in various jurisdictions of the study area by category of generator.

The report then considers the question of private and public expenditures for refuse removal and disposal, producing data on which economics and operations research studies may proceed. These data give reason to question the validity of estimates of the life span of existing landfill sites as more and more of the industrial and agricultural wastes are directed to such sites. Such estimates have obviously been made on the basis of domestic wastes plus such other wastes as are presently being brought to the site by private generators. Although this latter amount is considerable, it is not indicative of the total which can result from public restrictions on land use, incineration, and freedom to clutter up the environment with refuse. The potential is for near-crisis situations in landfill sites to develop even in areas where a considerable degree of complacency seems presently to be justified.

Operations Research

A series of models were developed which deal with wastes collection, treatment, and disposal in relation to the Comprehensive Wastes Generation Model described in the First Annual Report. Subjects receiving special consideration were:

1. Optimal location of treatment plants and disposal sites.
2. Determination of the least-cost flow pattern of wastes from origin, via transportation networks, to treatment plants, and ultimately to disposal sites.
3. Optimum operating policies for treatment plants with randomly varying wastes loads.

The models involved in the first two of these studies are presented in separate reports, one of which has already been released by the Project. The other is currently being prepared for publication as a separate report. (See references 2 and 3.) Brief descriptions of the models are included in Chapter IV. They deal with such subjects as Optimal Activity Locations and Determination of Optimal Wastes Flow Patterns.

Progress of the third subject — Optimization of Solid Wastes Treatment Plant Operations — is reported. Attention is directed to the specific problem of finding the service-rate rule that minimizes the long-term expected value of the cost rate, given on-site holding and processing costs. Two versions of this problem are explored:

1. A dual service-rate treatment facility with continuous arrival of wastes.
2. A continuous-rate treatment facility with periodic arrival of wastes.

A mathematical formulation of the problem is presented and the work yet to be done to complete the analysis is summarized.

Economics

Studies of the economic aspects of solid wastes management during the report period concerned three principal aspects:

1. The interrelationships of regional economics and the amount of wastes generated.
2. Economics of scale in solid wastes management.
3. Economic analysis of the five technologies under investigation in the project.

The first of these aspects is involved with the problems investigated by the planning team and is discussed in Chapter III as a part of the considerations involved in wastes generating potential of a region.

The second considers the way in which economies of scale might be utilized advantageously in a regional approach to solid wastes management; provided, of course, that such economies can be shown to exist in the collection, transport, and disposal aspects of wastes handling. On a purely rational basis, economies of scale might be expected in incineration, landfill, and composting provided the logistics of delivering wastes to the disposal site, or establishing the site itself, does not present insurmountable problems which offset scale. To get at the problem of economics of scale while avoiding the uncertainties of collection and site, it was concluded that existing installations might be the best source of interpretable data. A search of literature and study of recent surveys of solid wastes indicated that the same problems of missing detail encountered in the planning study hindered the analysis. It was therefore decided to seek information by means of a questionaire, beginning with incineration as the activity most likely to have data suitable for analysis by regression studies. Data collection is in progress but at the time of reporting it is too early to say whether it is possible on the basis of the haphazard past to determine whether economies of scale, which seem rationally possible, are overwhelmed by other practical problems inherent in the solid wastes generation system.

Low-Cost Biostabilization (Composting) System. A detailed analysis of the economic feasibility of low-cost biostabilization was undertaken for the purpose of deciding, if possible, both its future prospects on a practical scale and the value of proceeding further with investigative work. Consideration is given to land requirements; amount of wastes to be handled; processing needed; and other aspects of cities in the range of 25,000 to 250,000 populations. Specific calculations are made for a city of 100,000 based on assumptions and estimates which are set forth in the text of Chapter III. The results support the conclusion that low-cost biostabilization in which no attempt is made to sell the product appears to be comparable to other possible wastes processing methods; hence it cannot be ruled out of consideration on the basis of economics at the present stage of investigation.

Anaerobic Digestion. An analysis in which the assumptions which presently appear valid on the basis of investigative findings is presented in detail. It leads to the conclusion that although there may be reason to question the accuracy of assumptions, the indications are that digestion of organic refuse with sewage sludge cannot be ruled out on economic grounds insofar as the digestion process is concerned. A similar conclusion seems substantiated by the literature in regard to transport of wastes by sanitary sewers. No basis has been developed for judging whether the problems of assembling the overall organic wastes of a region and delivering them to sewage treatment plants in appropriate condition might overwhelm the economic prospects of aerobic digestion.

Biofractionation. The problems of biofractionation, which must be resolved before an accurate estimate can be made of its economic feasibility in relation to other alternate methods of handling organic wastes, are at present formidable.

Preliminary cost estimates presented in the text do not appear favorable to the process. There is reason to believe that reductions in the cost values on which the estimate is made might be reduced in the future. However, at the present it must be concluded that the process does not appear hopeful from an economic viewpoint as far as solid wastes management is concerned; and that in view of the status of the needed technology in comparison with the urgency of the problems of solid wastes management, the value of the investigation in its present context is questionable.

Wet Oxidation. Although the process of wet oxidation has not been applied to solid wastes in practice, there is enough experience with the system to provide a basis for an economic analysis at this time. However, where product generation rather than energy production is the basis for evaluation, uncertainties are introduced which must wait upon further experimentation for resolution. A cost analysis was therefore made on the basis of processing wastes only. Thereafter the possible reductions in cost from the sale of salvage and organic chemicals produced are considered. It is concluded that the process of wet oxidation cannot be ruled out at this time on the basis of economics, although a number of problems involved in scaling from pilot plant to prototype and in determining the spectrum of organic wastes which can be processed have yet to be evaluated economically.

Incineration-Pyrolysis. Among the advanced methods of refuse processing under study in the present research, the pyrolysis-combustion system ranks high in terms of economic feasibility. Indications are that costs per ton of wastes processed, both in terms of operation and capital, would be somewhat less than those for incineration. If the energy generated in the process is used to produce power, the estimates show a strong possibility for the process to become self-supporting. However, undue optimism about the process at this time should be tempered by the fact that the system, as developed in the present research, has not as yet been applied to solid wastes. However, it has been tried successfully with kraft black liquor, and there are no intrinsic reasons why it should not work with solid wastes.

Public Health

Significant differences are recognized between the planning, operations research, economic, and technological aspects of solid wastes management on the one hand, and public health on the other. The role of public health specialists, particularly those concerned with environmental health, is examined in relation to each of the three types of problems cited in Chapter II. Reasons are presented which explain the difficulty of relating solid wastes management directly to disease. Basically the fly and vector nuisance and disease threat which they represent is neither exclusively a solid wastes management problem, nor did the research which identified the hazards of such vectors derive from research on solid wastes *per se*. Granting that without proper management of solid wastes, effective control of fly borne and rodent borne diseases are difficult to control, the authors suggest that at present the type of public health threat they pose is more of a problem requiring eternal vigilance than a visible problem requiring definitive experimental research within a solid wastes management program.

Investigative and regulatory roles of public health specialists are identified in the text (Chapter VI). It is postulated that the interest of environmental health specialists in research is often much broader than that posed by solid wastes. Consequently such specialists bring to the solution of problems, such as occupational hazards and the sociological and psychological response of people to environmental conditions, the results of their own research in other aspects of the environment-man relationship than those identified specifically with solid wastes.

From considerations such as the foregoing the public health research team is involved in the overall research project more in an advisory and consulting than an experimental capacity.

The thrust of the experimental research activity in public health was directed to the third type of problem cited, i.e., those which remain unevaluated in comparison with more obvious hazards; or are still unidentified as problems in public health.

By means of five extensive tables, the research team undertook systematically to screen data on the types and composition of solid wastes originating in various human activities, as well as the fate of the numerous components or their breakdown products, for the purpose of:

1. Identifying those fractions which might have public health significance.
2. Evaluating the public health significance and environmental fate of the various fractions in relation to wastes processing or disposal.
3. Identifying those constituents of the solid wastes stream which merit intensive study, as well as the point in the management procedure where such study should begin.
4. Suggesting means of keeping those components shown to constitute a significant hazard from entering the environment in such a manner as to come in contact with man.

The skeleton or "work sheet" nature of the tables is stressed by the authors. Nevertheless, there is ample evidence to suggest a need for two types of research:

1. An accurate summary of the kind and amounts of individual materials or compounds which occur in the wastes of each of a vast number of human activities.
2. A study of the nature and amount of conversion products resulting from wastes management processes, particularly incineration.

A number of conclusions are presented, the most important being that at the present time there is more need for research teams on which public health specialists are prominent contributors along with scientists and technologists than for specific health-oriented studies. The five tables and the discussion presented does much to explain why it has been difficult to isolate public health research areas in the field of solid wastes even though rationally the subject is one of public health concern; and to suggest the direction health-oriented research should now take.

Technology

Anaerobic Digestion. The report (Chapter VII) shows that studies of feasibility of digesting the mixed organic wastes of a community, either with sewage sludge or alone, are well advanced. Acclimated sludge digesters to which green garbage was added were found to operate successfully with mixtures up to 76 percent garbage and 23 percent raw sewage sludge. Subsequent experiments with acclimated digesters led to the conclusion that such systems may be fed 100 percent garbage and still perform similarly to normal sewage sludge digesters in terms of solids reduction. Furthermore, garbage digesters are highly adaptable to varying proportions and quantities of feed — in fact, more so than are sludge digesters.

In experiments with paper pulp added to raw sewage solids it was found that degradation of the cellulose content was as much as 90 percent and that loadings of paper up to 60 percent of the total solids in the digester were feasible, i.e., until the resulting C:N ratio was 45:1. Digester failure occurred when the C:N ratio reached 52:1.

Experiments with paper pulp to which chicken manure was added as a source of nitrogen were conducted successfully. Paper pulp in quantities sufficient to bring the C:N ratio of the digester feed up to 70:1 digested satisfactorily with a reduction in cellulose content of some 90 percent.

In order to get some indication of the possibility of digesting demolition debris with sewage sludge, experiments were conducted with Monterey pine added to raw sewage solids. It was concluded that the pine was essentially inert to anaerobic digestion but that its resin content showed no evidence of toxic effects on the anaerobic organisms.

In all experiments in which cellulosic materials were added, there was a decrease in the fuel value of the digester gas, 7 to 10 percent at the most. This, however, seems to be of little consequence and there is at present no reason to suggest that anaerobic digestion might not be applied to the mixed organic wastes of a community.

Composting. The experimental work reported proceeded from the rationale that the land itself might be utilized as an essential part of the treatment of organic wastes by composting by taking advantage of the growth-decay cycle of nature prevailing in the soil. Two concepts of operation are under investigation. The first is intended to determine the limit of loading which the land can accept without loss of its ability to maintain the growth-decay cycle. The second would explore the loading limit when land is to be cropped seasonally simultaneously with its use as an acceptor of refuse. In both cases there is no intent to produce a salable product; and, more important, the land is expected to be dedicated to refuse disposal purposes only during the period of such dedication, in contrast with the landfill which restricts freedom to rededicate land to useful purpose once it has been set aside for fill.

Inasmuch as the experiments involve annual loading of land area at various rates (tons per acre per year) the research has not as yet yielded data necessary for final conclusions. However, the experiments are progressing according to plan and require but a small investment to maintain.

Wet Oxidation. Because the pilot plant installation for wet oxidation studies represents a sophisticated type of chemical engineering installation with adequate safety features and controls, this aspect of the investigation has only recently begun to produce data. Data on the successful operation of the equipment with white fir wood are reported. Chemical analyses of the fractions produced was under way at the time of preparation of this report. Operating parameters have been evaluated and a mass balance completed. Thus the first phase of the planned experimental work is essentially completed. In the second phase, organic material more representative of heterogenous mass of solid wastes will be fractionated.

Incineration-Pyrolysis. A pyrolysis operation designed according to the conventional sense of the term would result in the formation of a char, liquids, gas, and some ash. The difficulty inherent in such an operation is that unless a use can be found for these intermediates, excepting for the gas, they would in themselves constitute another disposal problem. To meet this difficulty, the concept of high temperature (900° to 1000°C) was followed in the design of a pilot-plant pyrolysis unit which can be used for pyrolyzing both kraft black liquor and solid wastes. At the high temperature, the only products would be gas and inert ash essentially free of carbon. The greater part of the construction has been completed at the time of this writing. The plant will have the capacity to process 200 pounds of solid wastes per hour.

Biofractionation. The biofractionation of solid wastes, like wet oxidation and perhaps, pyrolysis, depends for its success on the production of products having increased economic value. Thus it also involves the development of somewhat sophisticated reactor systems. However, since it also depends upon the successful utilization of living organisms rather than on physical environmental conditions, more is involved in reaching the point of data taking. The report presented in Chapter XI, therefore, concerns development of the process and the equipment, as well as the search for suitable microorganisms.

APPENDIX A

LIST OF DISPOSAL SITES

TABLE 44

DISPOSAL SITES IN ALAMEDA COUNTY

Code[a]	Name
A	Albany
B	Berkeley
C	Alameda
D	Davis Street (Oakland Scavenger Co.)
E	San Leandro Marina
F	West Winton (Oakland Scavenger Co.)
G	Fibreboard — Emeryville
H	Oakland Street Department
J	Alameda Naval Air Station
S	Turk Island Co.
T	Durham Rd. (Oakland Scavenger Co.)
W	Eastern Alameda Co.
X	Pleasanton

[a] Codes are those used on following maps.

TABLE 45

DISPOSAL SITES IN CONTRA COSTA COUNTY

Code	Name
C	Pittsburg
D	Antioch
H	Acme Fill
K	Martinez Rubbish
P	West Contra Costa Co.
	Sites not allocated to DSA:
E[a]	Ind. Tank Co. — Antioch
J[a]	Ind. Tank Co. — Vine Hill

[a] Both of these sites receive industrial wastes from the entire Bay Area.

TABLE 46

DISPOSAL SITES IN MARIN COUNTY

Code	Name
A	Redwood
C[a]	Angel Island
K	Martinelli (Point Reyes)
	Sites not allocated by DSA:
B	San Quentin (Not served by any scavenger company; used by public throughout Marin)
D	Ceccotti (Private demolition site)

[a] Angel Island State Park site is located in Marin County but is allocated to Western Contra Costa DSA.

TABLE 47

DISPOSAL SITES IN NAPA COUNTY

Code	Name
A	Upper Valley
B	Yountville Veterans' Home
C	Napa State Hospital
D	American Canyon
E	Calistoga Brush
F	Napa Brush
G	Napa Street Dept.
P	Del Santi

TABLE 48

DISPOSAL SITES IN SAN FRANCISCO COUNTY

Code	Name
A	Islais Creek
B	Hunters Point Naval Shipyard
C	Leonetti
D	Bodemix
E	San Francisco — North
F	Flora Crane
G	San Francisco — South
H	Loftus
J	Mirza (Candlestick — South)

TABLE 49

DISPOSAL SITES IN SAN MATEO COUNTY

Code	Name
A[a]	Sanitary Fill Co.
B	South San Francisco
C	Burlingame Rubbish
D	San Mateo Rubbish
E	San Mateo Scavenger Company
F	South County Disposal District
G	Hillside Rubbish
H	Colma Rubbish
Q	Daly City — Mussel Rock
R	Pacifica
S	Half Moon Bay
T	Half Moon Bay Rubbish
U	La Honda
V	Pescadero
W	Dolger

[a] The Sanitary Fill Company is located in San Mateo County but is allocated to the San Francisco Disposal Service Area.

TABLE 50

DISPOSAL SITES IN SANTA CLARA COUNTY

Code	Name
A	Palo Alto
B	Mountain View
C	Stierlin Rd. — Green Valley
D	Sunnyvale
E	Santa Clara
F	Edgewater
G	Los Altos Ranch
H	Newby Island
J	Customer Utility
K	Story Road
L	Singleton Road
M	San Jose
N	Eastside
P	Guadalupe
Q	Morgan Hill
W	Moffett Field NAS
T	Pacheco Pass
U	Gilroy
V	San Martin (closed March 7, 1967; reopened March 1, 1968)

TABLE 51

DISPOSAL SITES IN SOLANO COUNTY

Code	Name
A[a]	Mare Island Naval Shipyard
B	Travis Air Force Base
C	Fairfield
D	Solano County
E	Wheeler Island
J	Dixon
K	B & J
L	Rio Vista
M	California Medical Facility
N	Dixon Rubbish
Q[b]	Evers

[a] Mare Island Naval Shipyard is in Solano County but is allocated to the Napa County DSA.

[b] Evers site is in Solano County but is allocated to the Napa County DSA.

TABLE 52

DISPOSAL SITES IN SONOMA COUNTY

Code	Name
A	Sonoma
B	Sonoma State Home
C	Petaluma
D	Cloverdale
E	Healdsburg
F	Windsor
J	Roblar
K	Fort Ross State Park
L	Camp Royaneh
M	Korbel Winery
N	Bohemian Grove
P	Sonoma Coast State Park
Q	Los Guilicos Inst.
R	Santa Rosa Rubbish
S	Sea Ranch
G[a]	Guerneville
H	Occidental

[a] The Guerneville site receives solid wastes from the entire county as follows: (0901) Healdsburg, 8.75%; (0902) Santa Rosa, 17.5%; (0903) Western Sonoma, 65%; and (0904) South Sonoma, 8.75%. This is based on information received from local sources.

APPENDIX B

DEFINITION OF DISPOSAL SERVICE AREAS

TABLE 53

LIST OF DISPOSAL SERVICE AREAS AS DEFINED ACCORDING TO CENSUS TRACTS

County		Disposal Service Area		Census Tracts Included
Code	Name	Code	Name	
01	Alameda	0101	Berkeley	B 1-5; B 6 A-D; OK 1
		0102	Oakland	AB 1-5; B 6E; EM 6; OK 2-72; PI 7, 8; CV 22-28; SL 29-45; HA 46-68
		0103	Alameda	AL-9-16
		0104	Fremont	UC 69; FR 70-75; NE 76-77
		0105	Pleasanton	PL 21
		0106	Eastern Alameda County	LI 17-20
02	Contra Costa	0201	Western Contra Costa	59-92 Marin County: E 21-22; G 26-27; G 28^{a}; F 23-25; H 29-31
		0202	Central Contra Costa	14-56; 58
		0203	Eastern Contra Costa	1-13
03	Marin	0301	Western Marin	D 13; J 32; K 33; G 28^{a}
		0302	Eastern Marin	A 1-5; B 6-8; C 9-12; E 14-20
04	Napa	0401	Napa County	1-9 Solano County: A 1-19
05	San Francisco	0501	Richmond	All: D, E, F, G, H, I; J 5, J 14. Part: B 8, J 4, O 1
		0502	Marina-Pacific Heights	B 1-7, B 9-10, C 1, J 1-3, J 6 Part: J 4, B 8
		0503	Central	A 1-23 Part: J 9, J 11
		0504	South of Market	K 1, K 5 Part: L 1, K 2, K 3, K 4
		0505	Western Addition	J 7-8, 10, 12-13, 16-18 Part: J 9, 11, 19; N 2
		0506	Twin Peaks-Buena Vista	J 15, 20; N 3-6, 11-12 Part: O 1, N 13, J 19
		0507	South Van Ness	K 6, L 2; N 1, 7-10 Part: K 2, K 3, K 4, N 2
		0508	Potrero-Bayshore	L 4-5 Part: L 1
		0509	Outer Mission	L 3; M 1-3, 5-6, 9-11 Part: M 4
		0510	Southern Freeway – Mt. Davidson	M 7-8; N 14-15; O 5-6, 8B, 9 Part: M 4, N 13
		0511	Lake Merced	O 7, 8A; P 3B, 3C; R 1
		0512	Sunset	O 2-4; P 1-3A; Q 1

(Continued)

TABLE 53 (continued)

County		Disposal Service Area		Census Tracts Included
Code	Name	Code	Name	
06	San Mateo	0601	Daly City	10-19
		0602	South San Francisco	1-9; 24-25; 27-32; 37-38
		0603	Pacifica	20-23; 26
		0604	Central San Mateo	33-36; 39-64; 65[b]; 66-69; 71-94; 97-99
07	Santa Clara	0701	Palo Alto	O 106-116
		0702	Mountain View	N 92-99; M 91A[c]
		0703	Sunnyvale	M 84-90; L 82-83; F 46-47; M 91B[c]
		0704	Gilroy-Morgan Hill	V 123; W 124; X 125-126
		0705	Los Gatos	A 26-28; I 62-67; J 68A; J 68C[d]; J 69-72; K 73-76; Q 118; R 119
		0706	Los Altos	H 52-57; H 59-61; L 77-81; N 100-105; P 117 San Mateo County: 70, 95, 96, 65[b]
		0707	San Jose	A 1-25; A 29-32; B 33-35; C 36-42; D 43; E 44-45; G 48-50; H 51; H 58; S 120; J 68B[d]
		0708	Rest of County	T 121; U 122; Y 127
08	Solano	0801	Vacaville	V 30-32, C 29, C 33; D 34
		0802	Fairfield	B 20-21; C 22-23; C 28; C 35; F 24-27 Contra Costa County: 57
09	Sonoma	0901	Healdsburg	A, C[e]
		0902	Santa Rosa	D, E, C[e]
		0903	Western Sonoma	B
		0904	Southern Sonoma	F, G, H

[a] Marin County Census Tract G 28 is divided along the boundary line of Tamalpais Community Services District. The portion within the district is part of the Western Marin DSA; the remaining portion is part of the Western Contra Costa DSA.

[b] San Mateo County Census Tract 65 is divided: Incorporated portion is in the Central San Mateo DSA; the unincorporated portion is in the Los Altos DSA in Santa Clara County.

[c] Santa Clara County Census Tract M 91 is divided: M 91A is in the Mountain View DSA; M 91B is in the Sunnyvale DSA.

[d] Santa Clara County Census Tract J 68 is divided: J 68A and J 68C are in the Los Gatos DSA; J 68B is in the San Jose DSA.

[e] Sonoma County Census Tract C is divided along Eastwood Road and Highway 101. The Southern or "Windsor" portion is in the Santa Rosa DSA, the remaining portion is in Healdsburg DSA.

APPENDIX C

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES

TABLE 54

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES
ALAMEDA COUNTY

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0101	Berkeley	B	Berkeley	BE 1-5; 6A; 6B; 6C; 6D; OK 1
0102	Oakland	F D A E H G	West Winton (Oakland Scavenger Co.) Davis St. (Oakland Scavenger Co.) Albany San Leandro Marina Oakland Street Dept. Fibreboard – Emeryville	AB 1-5; B 6E; EM 6 OK 2-72; PI 7-8 CV 22-28; SL 29-45 HA 46-68
0103	Alameda	C J	Alameda Alameda Naval Air Station	AL 9-16
0104	Fremont	S T	Turk Island Site Durham Rd. (Oakland Scavenger Co.)	UC 69; FR 70-75 NE 76-77
0105	Pleasanton	X	Pleasanton	PL 21
0106	Eastern Alameda	W	Eastern Alameda County	LI 17-20

TABLE 55

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES
CONTRA COSTA COUNTY

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0201	Western Contra Costa	P C[a]	West Contra Costa Angel Island	59-92 Marin County; E 21-22; G 26-27; G 28[b]; F 23-25; H 29-31
0202	Central Contra Costa	H K	Acme Fill Martinez Rubbish	14-56; 58[c]
0203	Eastern Contra Costa	C D	Pittsburg Antioch	1-13
Sites not allocated by DSA:			[d]Industrial Tank Co. – Antioch – Map Code E [d]Industrial Tank Co. – Vine Hill – Map Code J	

[a] The Angel Island site is located in Marin County and serves Angel Island only. However, since it is part of Marin Census Tract F-24, it was combined with this DSA.

[b] Marin County Census Tract G 28 is divided between Western Marin DSA and Western Contra Costa DSA, following the boundaries of the Tamalpais Community Services District; all refuse from that district is disposed of in Western Marin, with the remainder of the census tract outside these boundaries part of the Contra Costa service area.

[c] Contra Costa Census Tract 57 is included in Solano County's Fairfield DSA.

[d] Both of these sites receive industrial wastes from the entire Bay Area.

TABLE 56

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES
MARIN COUNTY

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0301	Western Marin	K B	Martinelli (Point Reyes) San Quentin (7.71%)	D 13; J 32; K 33; G 28[a]
0302	Eastern Marin (See footnotes b, c, below)	A B	Redwood San Quentin (92.29%)	A 1-5; B 6-8; C 9-12; E 14-20
Sites not allocated by DSA:			San Quentin[d] — Map Code B Ceccotti — Map Code D	

[a] Marin County Census Tract G 28 is divided between Western Marin DSA and Western Contra Costa DSA, following the boundaries of the Tamalpais Community Services District; all refuse from that district is disposed of in Western Marin, with the remainder of the census tract outside these boundaries part of the Western Contra Costa Service Area.

[b] The Angel Island site is located in Marin County but is considered part of the Western Contra Costa DSA, as noted previously.

[c] The following Marin Census Tracts are part of Western Contra Costa DSA: E 21-22; G 26-27; G 28 (part); F 23-25; H 29-31.

[d] San Quentin site is open to the public. It accepts all solid wastes, except abandoned vehicles and hazardous wastes.

TABLE 57

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES
NAPA COUNTY

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0400	Napa County[a]	Q A B C D E F G P A[b]	Evers (Solano County) Upper Valley Yountville Veterans' Home Napa State Hospital American Canyon Calistoga Brush Napa Brush Napa Street Department Del Santi Mare Island Naval Shipyard	Napa 1-9 Solano County: A 1-19

[a] Napa County may be divided into 2 or 3 DSA's if more information becomes available. Due to overlapping of franchise areas, the county is treated as one DSA at present.

[b] The Mare Island Naval Shipyard is located in Solano County; inasmuch as it takes no refuse from outside the Mare Island Naval Shipyard's boundaries, it is allocated to this DSA since the surrounding area is all within the DSA.

TABLE 58

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES SAN FRANCISCO COUNTY

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0501 thru 0512	San Francisco County[a,b]	B	Hunters Point Naval Shipyard	All San Francisco County Census Tract
		A	Islais Creek	
		F	Flora Crane Company (Candlestick)	
		A[c]	Sanitary Fill Company	
		C	Leonetti	
		D	Bodemix	
		E	San Francisco - North	
		G	San Francisco - South	
		H	Loftus	
		J	Mirza (Candlestick - South)	

[a] From the disposal sites point of view, San Francisco could not be broken down to DSA level, but from auxiliary data on solid wastes, collection (truck) routes, the city and county of San Francisco has been divided into 12 DSA's (0501 - 0512). (See Table 59.)

[b] Treasure Island and Yerba Buena Island are included in the San Francisco Disposal Service Area.

[c] The Sanitary Fill Company site is located in San Mateo County.

TABLE 59

DISPOSAL SERVICE AREAS, CORRESPONDING TRUCK ROUTES, AND CENSUS TRACT BOUNDARIES
SAN FRANCISCO COUNTY

Disposal Service Area		Truck Route Number	Census Tracts
Code	Name		
0501	Richmond	Sunset: 1A-11A, 3, 34	D, E, F, G, H, I, J5, J14 (and parts of: B8, J4, 01)
0502	Marina-Pacific Heights	Sunset: 42, 33, 76, 80, 73 Golden Gate: 4, 7-9, 17, 18, 25, 28, 44, 47	B1-7, B9-10, C1, J1-3, J6 (and parts of: J4, B8)
0503	Central	Golden Gate: 2, 6, 10, 15, 16, 19-24, 26, 27, 30-32, 34, 36, 37, 41, 42, 45, 46, 48, 70, 73, 75	A1-23 (and parts of: J9, J11)
0504	South of Market	Golden Gate: 3, 5, 11, 12, 14, 33, 35, 38 Sunset: 4, 11	K1, K5 (and parts of: L1, K2-4)
0505	Western Addition	Sunset: 10, 14, 24, 27, 37, 53, 83, 85, 86	J7-8, 10, 12-13, 16-18 (and parts of: J9, 11, 19, N2)
0506	Twin Peaks-Buena Vista	Sunset: 5, 18, 22, 26, 30, 36, 38, 47, 51, 52, 87, 88	J15, 20, N3-6, N11-12 (and parts of: 01, N13, J19)
0507	South Van Ness	Sunset: 8, 12, 25, 35, 46, 56	N1, N7-10, K6, L2 (and parts of: N2, K2-4)
0508	Potrero-Bayshore	Sunset: 1, 6, 44, 71, 84	L4-5 (and parts of: L1)
0509	Outer Mission	Sunset: 7, 13, 15, 17, 21, 29, 49, 50	M1-3, L3, M5-6, M9-11 (and parts of: M4)
0510	So. Frway-Mt. Davidson	Sunset: 2, 9, 39. 41, 43, 54, 90, 91	N14-15, 05-6, 08B, 09, M7-8 (and Parts of: N13, M4)
0511	Lake Merced	Sunset: 16, 58, 63, 66, 72, 75, 77, 78	07, 08A, P3B, P3C, R1
0512	Sunset	Sunset: 20, 23, 31, 32, 45, 57, 60, 62, 64, 65, 70, 74, 82	02-4, P1-3A, Q1

TABLE 60

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES SAN MATEO COUNTY[a]

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0601	Daly City	G Q W	Hillside Rubbish Daly City — Mussel Rock Dolger	10-19
0602	South San Francisco	B H C	South San Francisco Colma Rubbish Burlingame Rubbish	1-9; 24-25; 27-32; 37-38
0603	Pacifica	R	Pacifica	20-23; 26
0604	Central San Mateo	D E F S T U V	San Mateo Rubbish San Mateo Scavenger Company South County Disposal District Half Moon Bay Half Moon Bay Rubbish La Honda Pescadero	33-36; 39-64; 65[b]; 66-69; 71-94; 97-99

[a] The Sanitary Fill Company is located in San Mateo County but is allocated to to the San Francisco Disposal Service Area.

[b] San Mateo Census Tract 65 is divided; the incorporated portion is in the Central San mateo DSA, and the unincorporated portion is in Los Altos DSA, Santa Clara County. The remaining San Mateo Census Tracts 70, 95, and 96 are also in the Los Altos DSA.

TABLE 61

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES SANTA CLARA COUNTY

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0701	Palo Alto	A	Palo Alto	O 106-116
0702	Mountain View	B C	Mountain View Stierlin Road – Green Valley	N 92-99; M 91[a]
0703	Sunnyvale	D W	Sunnyvale Moffett Field NAS	M 84-90; L 82-83; F 46-47; M 91B[a]
0704	Gilroy-Morgan Hill	U T Q V	Gilroy Pacheco Pass Morgan Hill San Martin Disposal site (closed 3-7-67; reopened 3-1-68)	V 123; W 124; X 125-126
0705	Los Gatos	P	Guadalupe	A 26-28; I 62-67; J 68A[b]; J 68C[b]; J 69-72; K 73-76; Q 118; R 119
0706	Los Altos	G E F	Los Altos Ranch Santa Clara Edgewater	H 52-57; H 59-61; L 77-81; N 100-105; P 117 San Mateo County: 70, 95, 96, 65[c]
0707	San Jose	H N J K M L	Newby Island Eastside Customer Utility Story Road San Jose Singleton Road	A 1-25; A 29-32; B 33-35; C 36-42; D 43; E 44-45; G 48-50; H 51; H 58; S 120; J 68B[b]
0708	Remainder of County		Mt. Madonna Park Site (closed – hence this DSA may be merged with 0704)	T 121, U 122, Y 127

[a] Santa Clara County Census Tract M 91 is divided: M 91A in Mountain View DSA; M 91B in Sunnyvale DSA.

[b] Santa Clara County Census Tract J 68 divided: J 68A and J 68C in Los Gatos DSA; J 68B in San Jose DSA.

[c] San Mateo County Census Tract 65 is divided: incorporated portion in Central San Mateo DSA, unincorporated protion in Los Altos DSA.

TABLE 62

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES SOLANO COUNTY[a]

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0801	Vacaville	K J M N	B & J Dixon California Medical Facility Dixon Rubbish	V 30-32; C 29; C 33; D 34
0802	Fairfield	D B C L E	Solano County[b] Travis Air Force Base Fairfield Rio Vista Wheeler Island[c]	B 20-21; C 22-23; C 28; C 35; F 24-27; Contra Costa County: 57

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[a] Mare Island Naval Shipyard is located in Solano County but is allocated to Napa County DSA.

[b] Solano County Census Tracts A 1-19 are allocated to Napa County DSA.

[c] Wheeler Island receives dredgings from San Francisco Bay.

TABLE 63

DISPOSAL SERVICE AREAS, CORRESPONDING DISPOSAL SITES, AND CENSUS TRACT BOUNDARIES SONOMA COUNTY

Disposal Service Area		Sites Allocated		Census Tracts
Code	Name	Code	Name	
0901	Healdsburg	E D G	Healdsburg Cloverdale Guerneville (8.75%)[b]	A, C[a]
0902	Santa Rosa	F R Q G	Windsor Santa Rosa Rubbish Los Guilicos Inst. Guerneville (17.5%)[b]	D, E, C[a]
0903	Western Sonoma	G P K L M N S H	Guerneville (65.0%)[b] Sonoma Coast State Park Fort Ross State Park Camp Royaneh Korbel Winery Bohemian Grove Sea Ranch Occidental	B
0904	Southern Sonoma	G J B C A	Guerneville (8.75%)[b] Roblar Sonoma State Home Petaluma Sonoma	F, G, H

---

[a] Sonoma County Census Tract C is divided along Eastwood Road and Highway 101. Southern (Windsor) portion is part of the Santa Rosa DSA; the remainder is part of Healdsburg DSA.

[b] For explanation, see Table 52 (Appendix A).

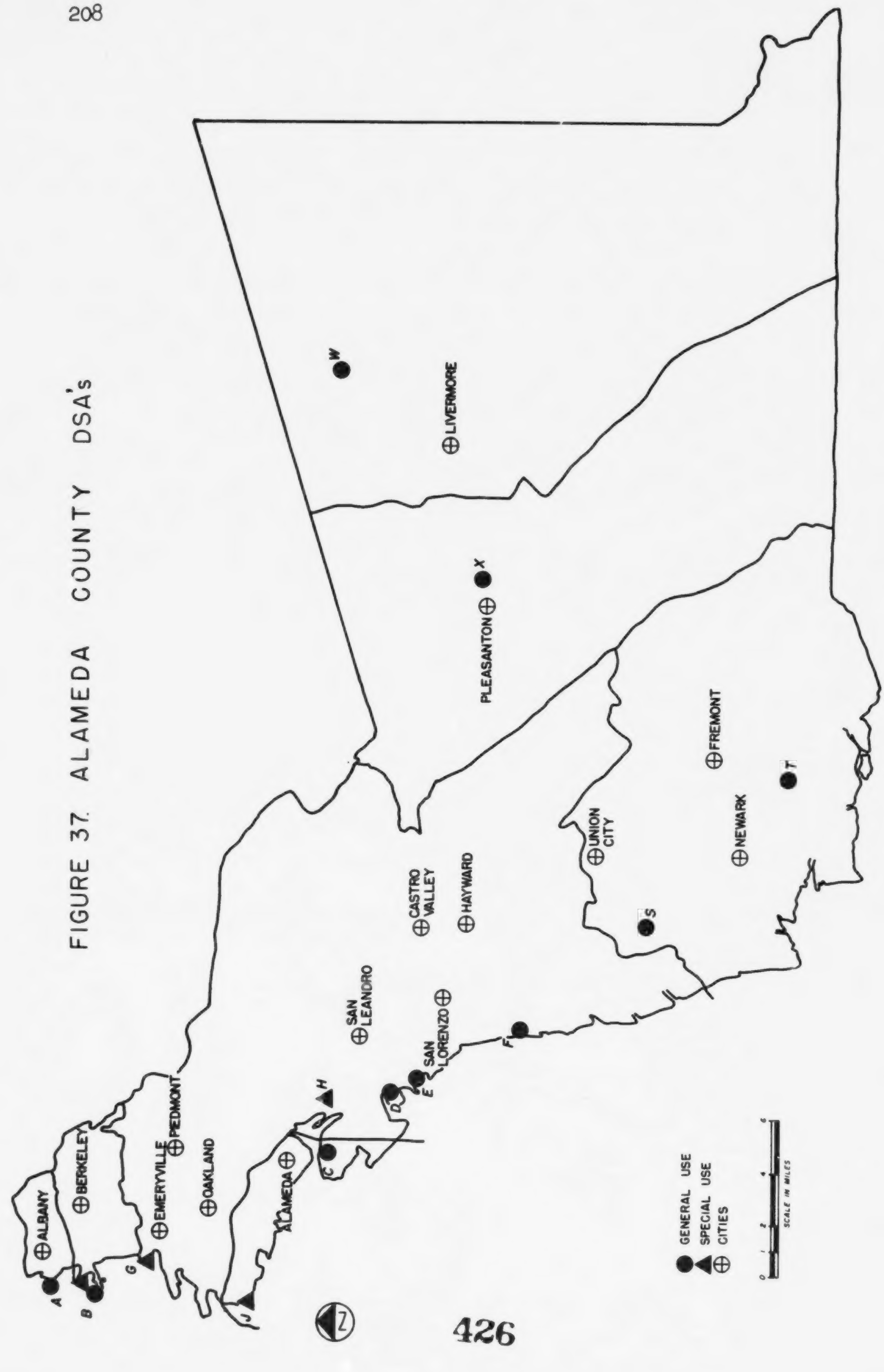


FIGURE 37. ALAMEDA COUNTY DSA's

ALBANY
BERKELEY
EMERYVILLE
PIEDMONT
OAKLAND
ALAMEDA
SAN LEANDRO
SAN LORENZO
CASTRO VALLEY
HAYWARD
UNION CITY
NEWARK
FREMONT
PLEASANTON
LIVERMORE
A
B
G
J
C
H
D
E
F
S
T
X
W
GENERAL USE
SPECIAL USE
CITIES
0
1
2
4
6
SCALE IN MILES
N

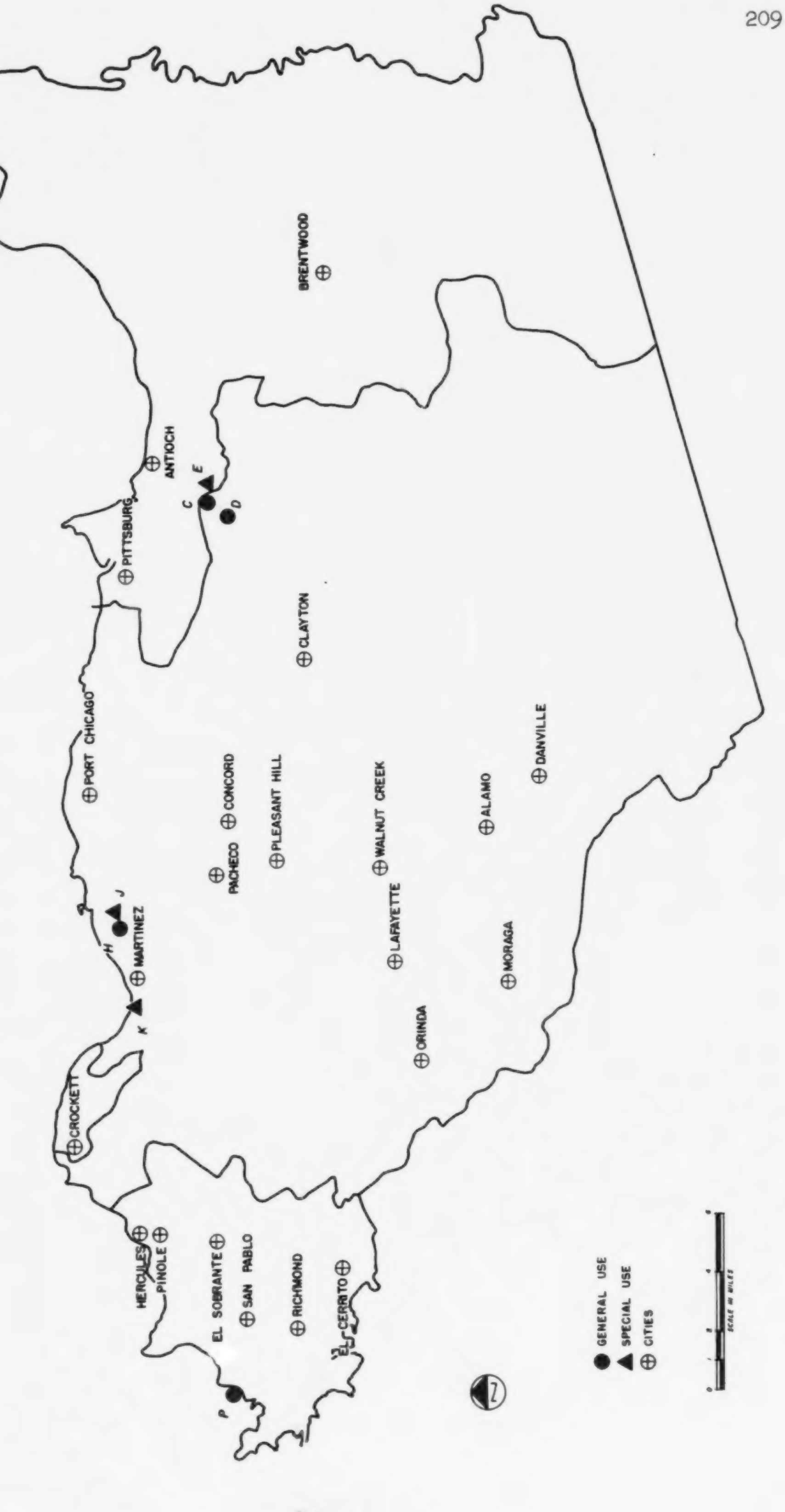
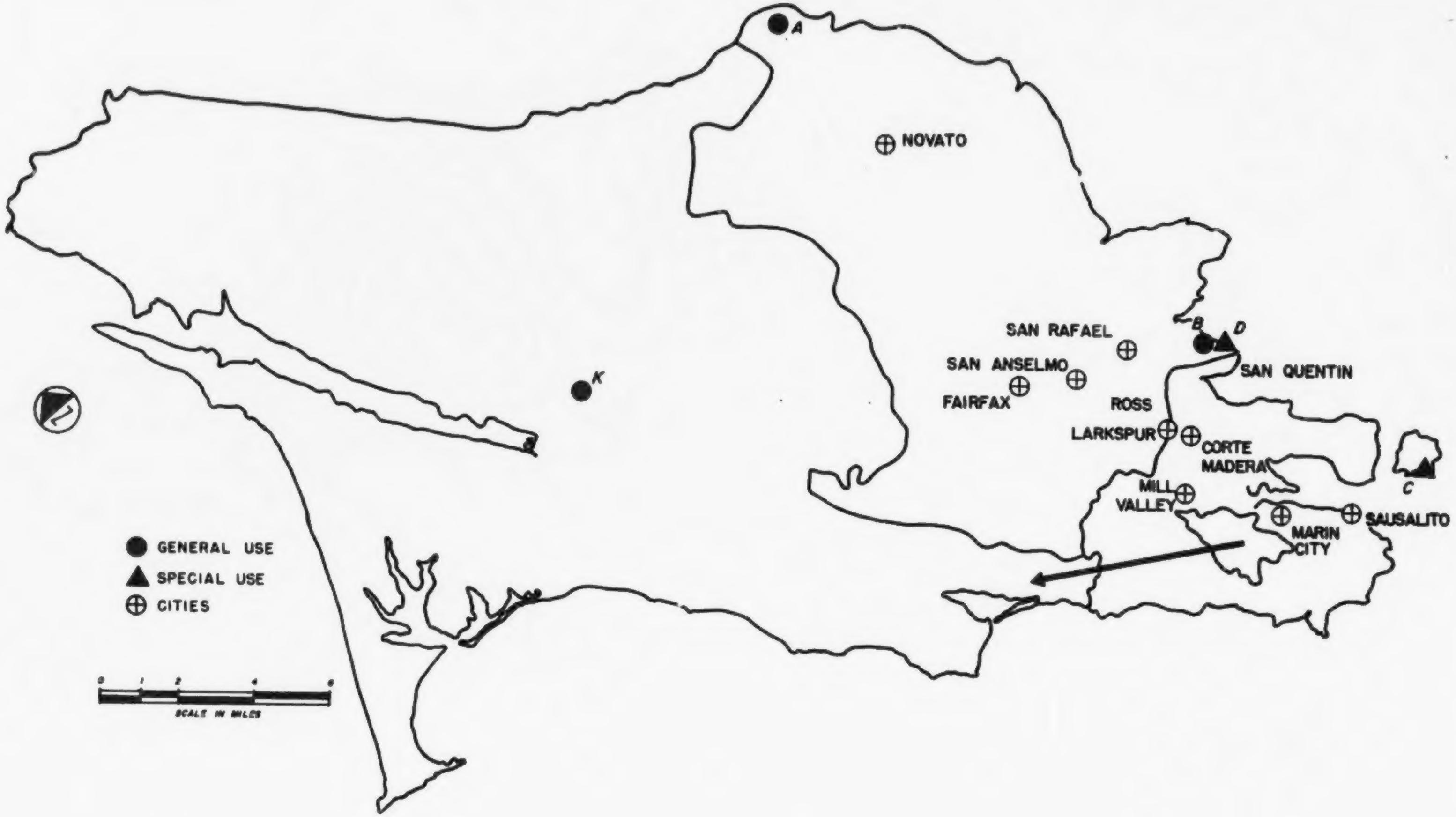


FIGURE 38 CONTRA COSTA COUNTY DSA's

BRENTWOOD
ANTIOCH
PITTSBURG
CLAYTON
PORT CHICAGO
CONCORD
PLEASANT HILL
PACHECO
WALNUT CREEK
LAFAYETTE
ALAMO
DANVILLE
MORAGA
ORINDA
MARTINEZ
CROCKETT
HERCULES
PINOLE
EL SOBRANTE
SAN PABLO
RICHMOND
EL CERRITO
C
D
E
H
J
K
P
N
● GENERAL USE
▲ SPECIAL USE
⊕ CITIES
SCALE IN MILES

FIGURE 39. MARIN COUNTY DSA's


A
NOVATO
SAN RAFAEL
SAN ANSELMO
FAIRFAX
ROSS
LARKSPUR
CORTE MADERA
MILL VALLEY
MARIN CITY
SAUSALITO
SAN QUENTIN
B
D
C
K
● GENERAL USE
▲ SPECIAL USE
⊕ CITIES
0 1 2 4 6
SCALE IN MILES

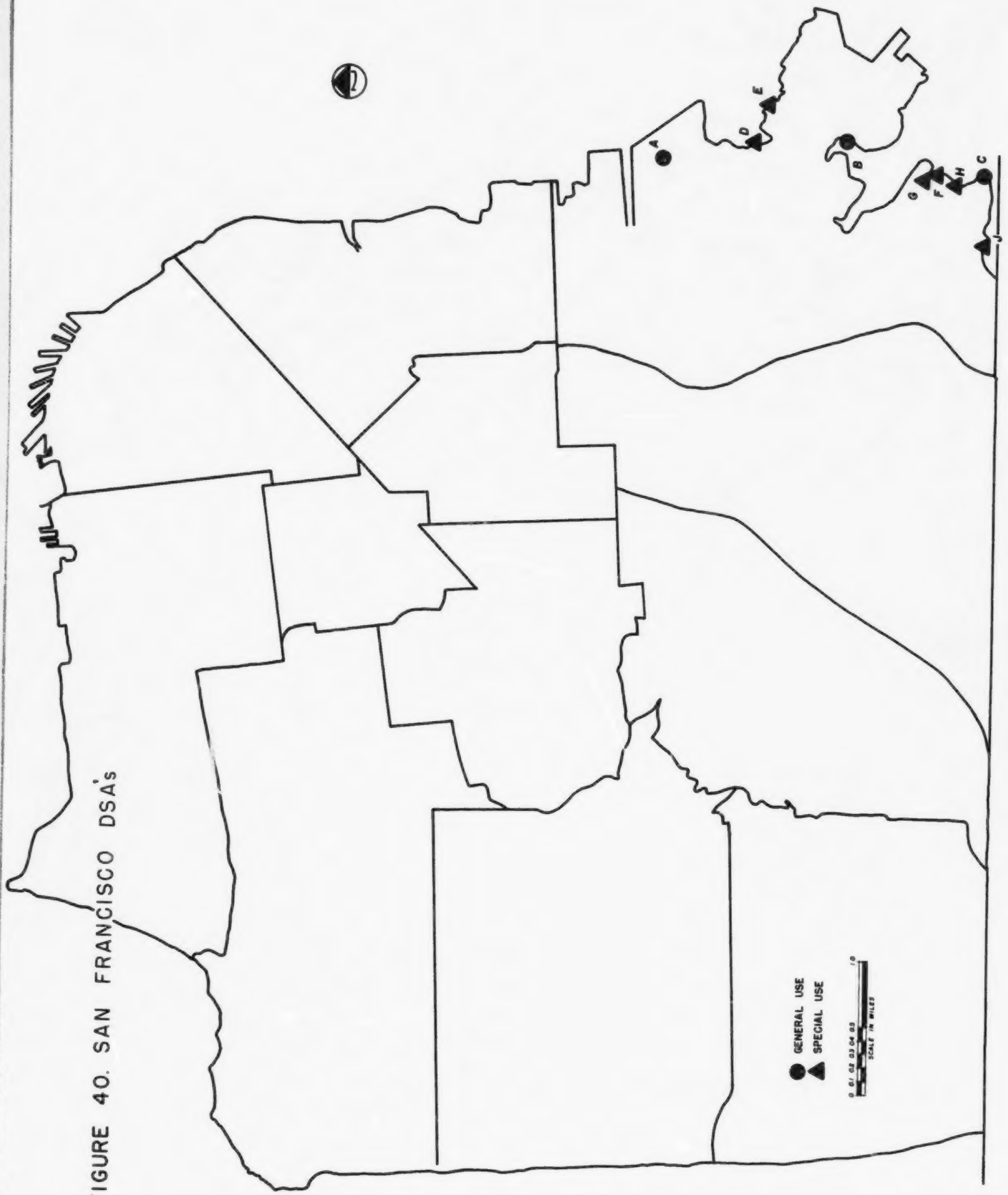

A
B
C
D
E
F
G
H
J
2
GENERAL USE
SPECIAL USE
0 0.1 0.2 0.3 0.4 0.5 1.0
SCALE IN MILES

FIGURE 40. SAN FRANCISCO DSA's

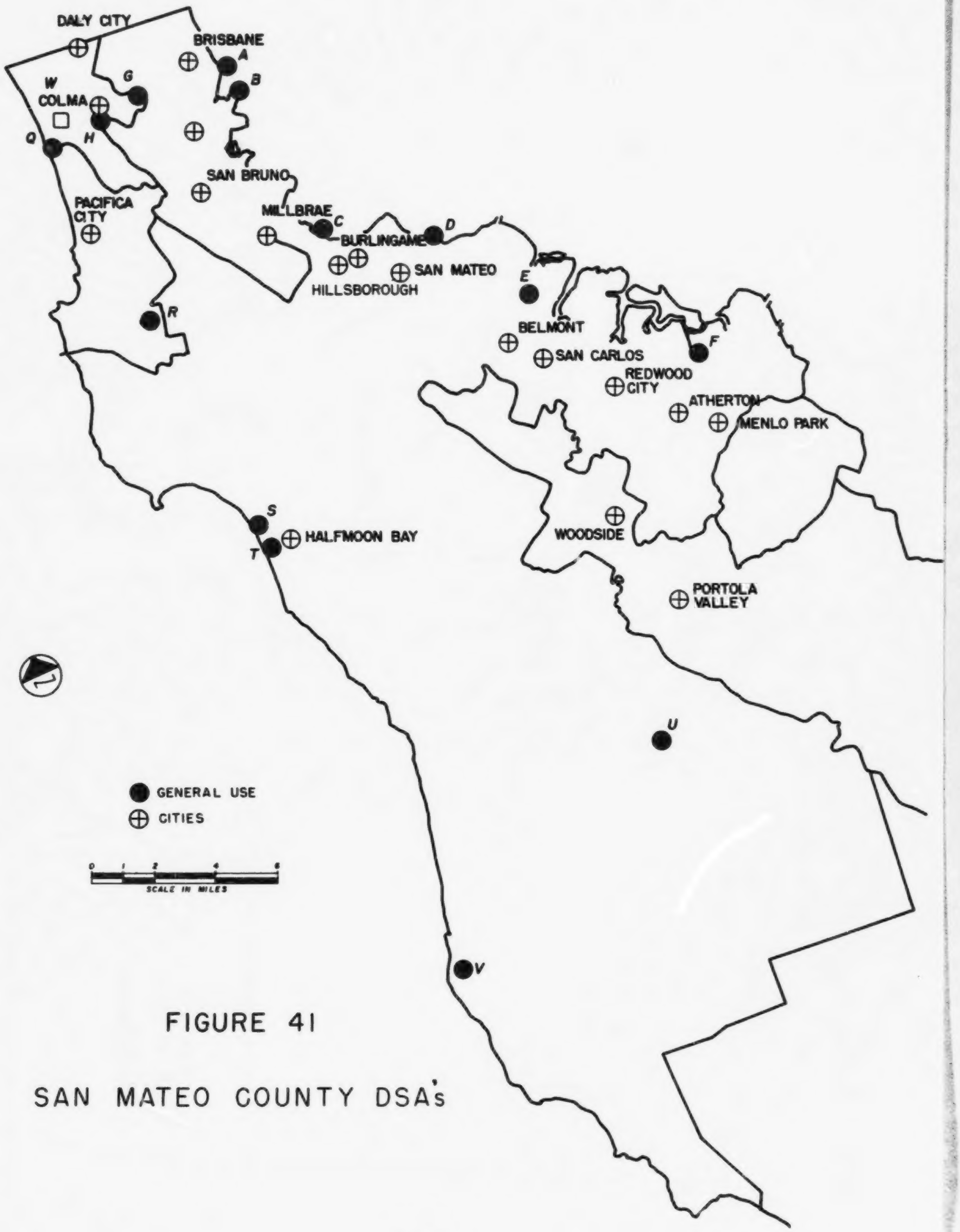
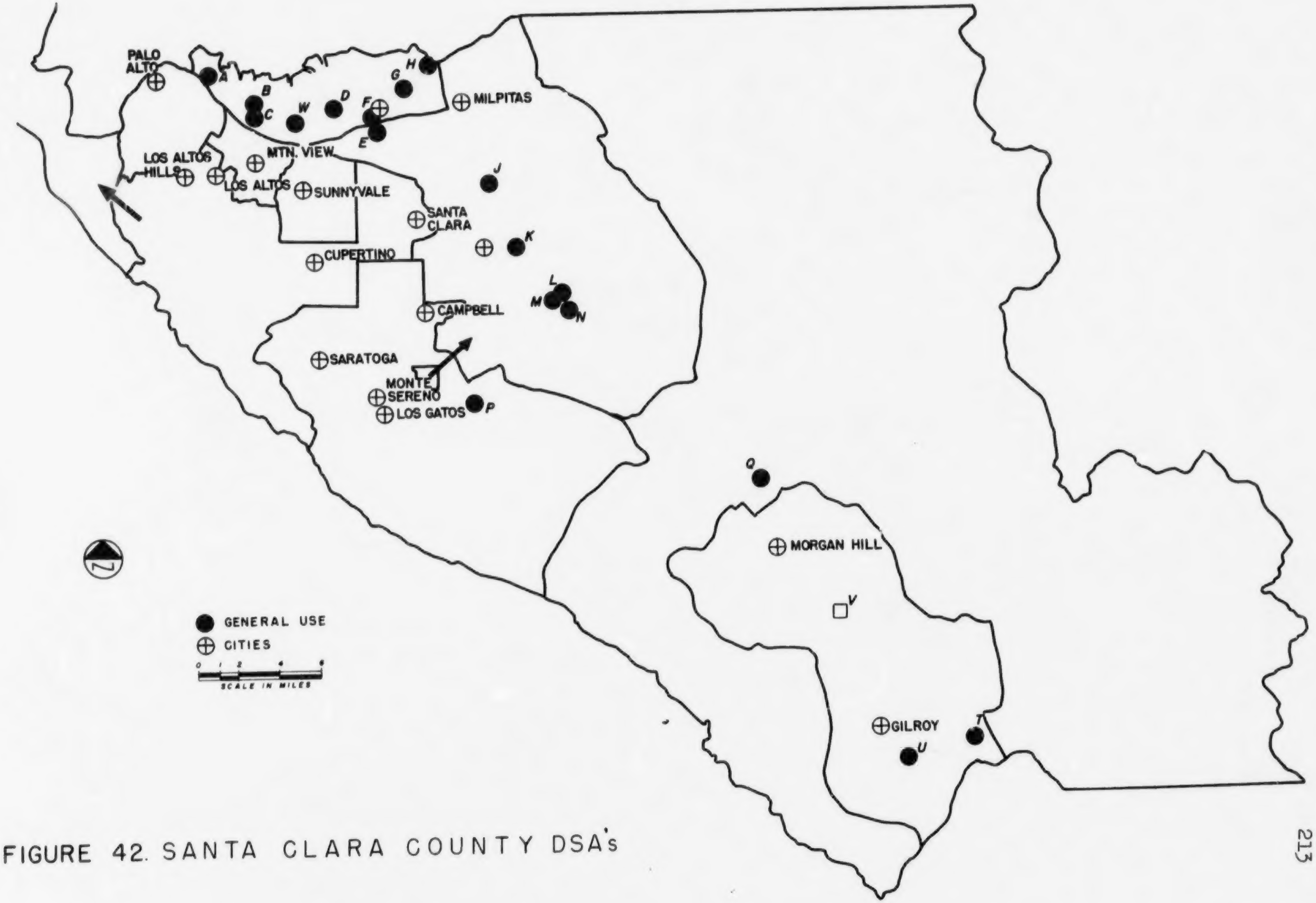

DALY CITY
BRISBANE
A
B
G
W
COLMA
H
Q
SAN BRUNO
PACIFICA CITY
MILLBRAE
C
BURLINGAME
D
SAN MATEO
HILLSBOROUGH
E
R
BELMONT
SAN CARLOS
F
REDWOOD CITY
ATHERTON
MENLO PARK
S
T
HALFMOON BAY
WOODSIDE
PORTOLA VALLEY
U
V
● GENERAL USE
⊕ CITIES
0
1
2
4
6
SCALE IN MILES

FIGURE 41

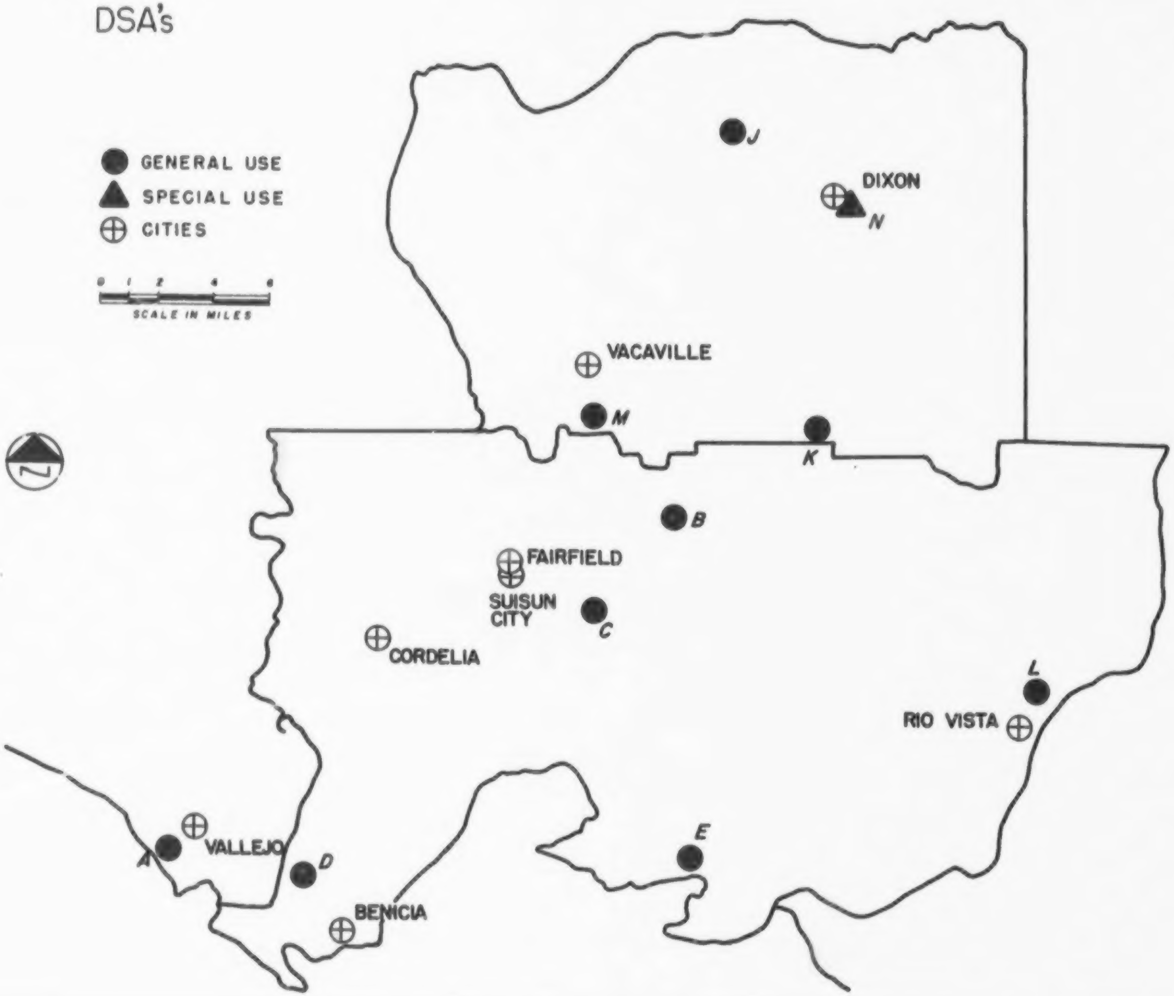
SAN MATEO COUNTY DSA's



PALO ALTO
A
B
C
W
D
F
E
G
H
MILPITAS
LOS ALTOS HILLS
MTN. VIEW
LOS ALTOS
SUNNYVALE
J
SANTA CLARA
K
CUPERTINO
L
M
N
CAMPBELL
SARATOGA
MONTE SERENO
LOS GATOS
P
Q
MORGAN HILL
V
GILROY
U
T
GENERAL USE
CITIES
0 1 2 4 6
SCALE IN MILES

FIGURE 42. SANTA CLARA COUNTY DSA's

FIGURE 43.
SOLANO
COUNTY
DSA's


GENERAL USE
SPECIAL USE
CITIES
0 1 2 4 6
SCALE IN MILES
N
J
DIXON
N
VACAVILLE
M
K
B
FAIRFIELD
SUISUN CITY
C
CORDELIA
L
RIO VISTA
E
A
VALLEJO
D
BENICIA

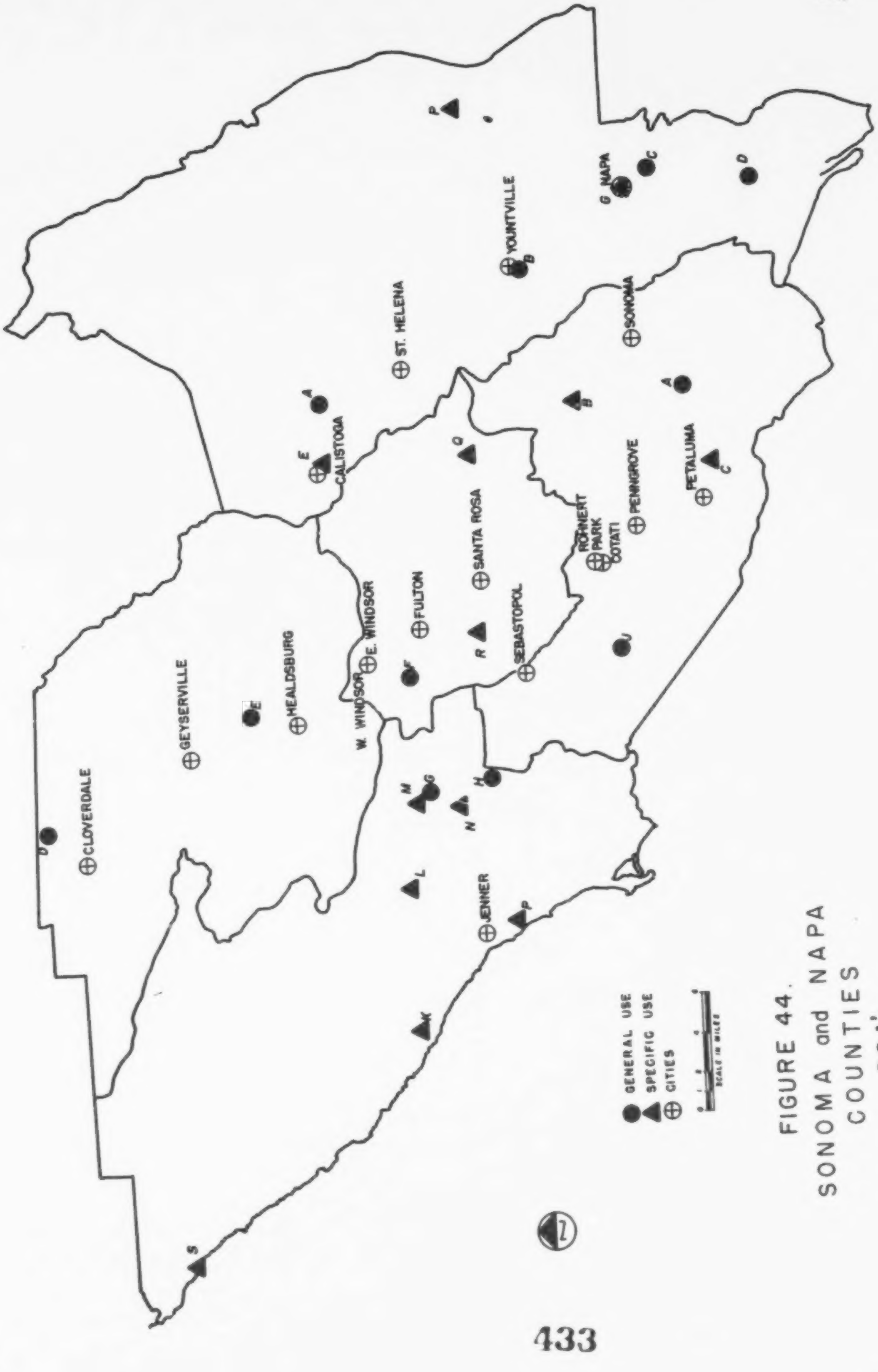

CLOVERDALE
GEYSERVILLE
HEALDSBURG
W. WINDSOR
E. WINDSOR
FULTON
SANTA ROSA
SEBASTOPOL
ROHNERT PARK
COTATI
PENNGROVE
PETALUMA
SONOMA
CALISTOGA
ST. HELENA
YOUNTVILLE
NAPA
JENNER
A
B
C
D
E
F
G
H
J
K
L
M
N
P
Q
R
S
GENERAL USE
SPECIFIC USE
CITIES
SCALE IN MILES

FIGURE 44.
SONOMA and NAPA
COUNTIES
DSA's

APPENDIX D

SOLID WASTES CLASSIFICATIONS BY POINT OF ORIGIN

TABLE 64

SOLID WASTES CLASSIFICATIONS BY POINT OF ORIGIN

1.	RESIDENTIAL:	Residential units including single-family dwellings, apartments, public housing, trailers, permanent rooming houses, membership lodgings, residence halls, and dormitories. 1a. Single-family units 1b. Multiple-family units
2.	RESTAURANTS and HOTELS:	As in SIC 58 and 70.
3.	PRIVATE INSTITUTIONS:	Schools, colleges (not including residence halls).
4.	OFFICES and PUBLIC FACILITIES:	Public hospitals, jails, prisons, schools, colleges, and universities (not including residence halls); all governmental offices, parks and recreation facilities; cultural facilities, zoos, stadia; post offices, courts; service facilities such as police and fire stations; health clinics. Facilities and services relating to public streets, highways, alleys, malls, and plazas, and litter cans and baskets associated with these facilities; sewage treatment plants; public water systems, other publicly run utilities; rapid transit, street car and city buses and their facilities; public ports; nonmilitary airports; weather stations.
5.	HEALTH SERVICES (PRIVATE):	Private hospitals, nursing homes, convalescent homes, etc.
6.	COMMERCIAL and SERVICE ESTABLISHMENTS (PRIVATE):	Stores, markets, offices (including government), private cultural and amusement centers, including wholesale and retail stores, professional services, banks, offices of all kinds, professional and trade schools, police and fire departments, auto repair, personal service businesses, funeral services, race tracks, resorts, veterinarians and animal hospitals and kennels, cemeteries and crematoriums; services involving transportation, communication, electricity, water, and gas wastes. Includes port facilities, bus depots, railroad stations and shops, airports, etc.
7.	CONSTRUCTION and DEMOLITION (PRIVATE AND PUBLIC):	Building construction, general contracting; plumbing, heating and air conditioning; painting, electrical services, masonry, plastering, carpentry, concrete services; well-drilling services; wrecking contractors; large-scale public construction and demolition projects such as urban renewal, freeway building, BART.
8.	AGRICULTURE:	Croplands, orchards, vineyards, pasturelands; dairies and poultry farms; feedlots; greenhouses and nurseries; other ranch lands; fisheries and marine products; commercial forest lands. (Divided into 11 categories as in text.)
9.	EXTRACTIVE INDUSTRY:	Metal ore mining, mineral mining; sand and gravel quarries; stone quarries; clay, ceramic and refractory mining; dredging services; salt products, coal.

10.	CANNING and PRESERVING:	Canneries (same as in SIC 203).

MANUFACTURING INDUSTRY

11.	OTHER FOOD PROCESSING:	Meat and dairy products; (SIC 20, excluding SIC 203); vegetables and seafoods; grain mill products; bakery products; sugar; candy; nuts; chocolate and chewing gum; beverages including breweries, wineries, soft drinks; vegetable oils; animal and marine fats and oils; coffee; pasta products; ice; and other food preparation and kindred products manufacturing.
12.	TOBACCO INDUSTRY:	Cigars, cigarettes, pipe tobacco, and kindred products.
13.	ORDNANCE and ACCESSORIES:	Ordnance and explosives (missiles), tanks; guns, small arms; other ordnance and accessories manufacturing. (Does not include nuclear weapons.)
14.	TEXTILES and APPAREL:	Fabrics and apparel made of cotton, wool, silk, synthetic fibers; knit goods, yarn and thread; rugs and carpets; felt goods; upholstery padding; tire cord and fabrics, other textile goods.
15.	LUMBER and WOOD PRODUCTS:	Sawmills, planing mills; manufacturing of plywood, veneer, millwork, prefabricated structural wood products; wooden containers; other lumber and wood products. (Does not include furniture.)
16.	FURNITURE and FIXTURES:	Household and office furniture; partitions, shelves, office and store fixtures; lockers, cabinets, bedsprings, bedframes, venetian blinds, mattresses.
17.	PAPER and ALLIED PRODUCTS:	Pulp, paper, paperboard, paper coatings and finishings; converted paper and paperboard products; boxes and containers; building paper and building board.
18.	PRINTING, PUBLISHING, and ALLIED:	Newspapers, periodicals, books, commercial printing, greeting card manufacturing, etc.
19.	CHEMICALS and ALLIED PRODUCTS:	Industrial inorganic and organic chemicals; plastics and synthetics; drugs; soaps, detergents, and other cleaning preparations; paints, varnishes, etc.; gum wood chemicals; agricultural chemicals; other chemical and allied products.
20.	PETROLEUM REFINING:	Petroleum refining; other petroleum products, lubricating oils and greases; paving mixtures and roofing materials; asphalt felt.
21.	RUBBER and PLASTIC PRODUCTS:	Tires and inner tubes; rubber footwear; miscellaneous rubber and plastic products.
22.	LEATHER and ALLIED:	Shoes, boots, handbags, cases, luggage, gloves, belts, leather garments.
23.	STONE, CLAY, and GLASS:	Glass and glassware, cement (hydraulic), structural clay products including brick, ceramic and clay tile; pottery and related products including chinaware, electrical porcelain; concrete, gypsum, and lime; plaster products manufacturing.

24.	PRIMARY METALS:	Blast furnaces, steel works, rolling and finishing of ferrous metals; iron and steel foundries; primary and secondary smelting and refining of nonferrous metals.
25.	FABRICATED METALS:	Metal cans, cutlery, hand tools, and general hardware; plumbing fixtures; heating equipment (nonelectrical); screws and nails; wire.
26.	NONELECTRICAL MACHINERY:	Engines and turbines; farm machinery and equipment; construction, mining and material handling equipment; special and general industrial and office machinery; office, computing, accounting and other service industry machines.
27.	ELECTRICAL MACHINERY:	Electrical transmission and distribution equipment; electrical industrial apparatus; household appliances; lighting and wiring equipment; radio, television and other communication equipment, electronic components; other electrical manufacturing.
28.	TRANSPORTATION EQUIPMENT:	Motor vehicles and motor vehicle equipment; aircraft and parts; ship and boat building and repairing; railroad equipment; motorcycles and bicycles and parts.
29.	PROFESSIONAL and SCIENTIFIC INSTRUMENTS:	Engineering, laboratory, and scientific research instruments and associated equipment; instruments for measuring, controlling and indicating physical characteristics; optical instruments and lenses; surgical, medical and dental instruments and supplies; opthalmic goods; photographic equipment and supplies; watches, clocks and clockwork devices.
30.	MISCELLANEOUS MANUFACTURING:	Jewelry, silverware, and other precious metal work; musical instruments and parts; toys, novelties; athletic equipment, games; pens, pencils, artist supplies; costume jewelry, buttons, and miscellaneous other notions; brooms, brushes; signs and advertising displays.
31.	NONCLASSIFIABLE ESTABLISHMENTS:	Other establishments that can not be classified into any of the thirty sources defined above.

APPENDIX E

MULTIPLIERS FOR LARGE AND SMALL FIRMS

TABLE 65

LARGE-FIRM MULTIPLIERS

Standard Industrial Classification		Employment 1[a]	Annual Wastes Vol. cu yd 2[b]	Annual Wastes per Employee cu yd 3[c]
SIC No.	Title			
19	Ordnance and Accessories	29,356	131,404	4.476
203	Canning and Preserving[d]	11,389	102,238	8.977
20	Other Food Processing (Except 203)	2,012	17,545	8.720
21	Tobacco	e	e	e
22	Textiles	e	e	e
23	Apparel	601	1,248	2.077
24	Lumber and Wood Products	e	e	e
25	Furniture and Fixtures	e	e	e
26	Paper and Allied Products	250	9,360	37.440
27	Printing, Publishing, and Allied	968	7,020	7.252
28	Chemicals and Allied	e	e	e
29	Petroleum Refining	e	e	e
30	Rubber and Plastics	481	9,069	18.854
31	Leather	e	e	e
32	Stone, Clay, Glass, and Concrete	1,258	6,617	5.260
33	Primary Metals	e	e	e
34	Fabricated Metal Products	3,565	47,078	13.206
35	Nonelectrical Machinery	8,872	101,153	11.401
36	Electrical Machinery	7,807	57,252	7.333
37	Transportation Equipment	4,100	100,776	24.580
38	Instruments	e	e	e
39	Miscellaneous Manufacturing Industries	e	e	e

[a] Column 1: Data on employment were obtained for those large firms which were surveyed and included in the wastes calculation from the research department of the Association of Metropolitan San Jose (Greater San Jose Chamber of Commerce).

[b] Column 2: FMC report, Solid Waste Disposal System Analysis (Preliminary Report), Tables 10 and 11, 1968. [3]

[c] Column 3: Column 2/Column 1

[d] For Canning and Preserving (SIC 203), no individual firm data were available. The industry total developed for the county as a whole was divided by the total employment in the industry (specially tabulated) to arrive at the multiplier. See text for further explanation.

[e] Data not available.

TABLE 66

SMALL-FIRM MULTIPLIERS

Standard Industrial Classification		Weekly Wastes Vol. per Firm cu yd 1[a]	Annual Wastes Vol. per Firm cu yd 2[b]	Average Employment per Firm 3[c]	Annual Waste Vol. per Employee cu yd 4[d]
SIC No.	Title				
19	Ordnance and Accessories	2.500	130.00	e	e
203	Canning and Preserving		(Not Surveyed)		
20	Other Food Processing (Except 203)	10.875	565.50	26.979	20.961
21	Tobacco		N. A.		
22	Textiles		N. A.		
23	Apparel	4.000	208.00	5.882	35.360
24	Lumber and Wood Products	16.083	836.33	17.247	48.492
25	Furniture and Fixtures	23.000	1,196.00	13.767	86.877
26	Paper and Allied Products	44.650	2,321.80	35.479	65.442
27	Printing, Publishing, and Allied	6.448	335.29	13.289	25.230
28	Chemicals and Allied	6.506	338.31	18.439	18.348
29	Petroleum Refining	e	e	e	e
30	Rubber and Plastics	5.275	274.30	9.596	28.583
31	Leather	e	e	e	e
32	Stone, Clay, Glass, and Concrete	9.415	489.60	16.747	29.235
33	Primary Metals	2.000	104.00	23.409	4.443
34	Fabricated Metal Products	5.284	274.75	12.951	21.214
35	Nonelectrical Machinery	4.450	231.40	12.921	17.909
36	Electrical Machinery	6.733	350.13	21.036	16.645
37	Transportation Equipment	4.550	236.60	16.490	14.348
38	Instruments	3.600	187.20	20.933	8.943
39	Misc. Manufacturing Industries	1.250	65.00	10.931	5.946

[a] Column 1: Data obtained and calculated for each SIC on the basis of small firm questionnaire responses supplied by FMC.

[b] Column 2: Weekly average in Column 1 multiplied by 52.

[c] Column 3: Average size of small firm estimated from the distribution of firms by employment size, supplied by the California Department of Employment (Research and Statistics), San Francisco Office.

[d] Column 4: Column 2/Column 3.

[e] Data not available.

APPENDIX F

POPULATION DATA SOURCES

TABLE 67

POPULATION DATA SOURCES, SPECIAL PROBLEMS AND SOLUTIONS BY COUNTY

All population data has been recorded by disposal service area and by census tract within the disposal service area where possible. In certain instances, the disposal service area boundary line divided a census tract. These special problems and the method of resolution are indicated below.[a]

METHOD OF ESTIMATION BY COUNTY

1. ALAMEDA	No census tracts were split, but county uses a planning unit for data collections that combines census tracts. In all instances, the data for individual tracts that was necessary was available.
2. CONTRA COSTA	The Western Contra Costa DSA contains several Marin County census tracts, one of which (G 28) was divided between this DSA and Western Marin County DSA. Special estimates from Marin County made for a recent election were utilized to make an accurate division of population.
3. MARIN	See Contra Costa, above.
4. NAPA	Franchises let for refuse collection in Napa have boundary lines that cross through census tracts in every direction. Given the small population of the county, much less than many of other DSA's, and the difficulty of achieving accurate data, it was decided to treat the county as one disposal service area.
5. SAN FRANCISCO	The City and County of San Francisco have coterminus boundaries. It was divided into twelve DSA's for some calculations and treated as one DSA for others. The separation into twelve DSA's was made to coincide with truck routes, and involved splitting thirteen census tracts. Population estimates of the portions were made by staff on the basis of residential land use block data obtained from the San Francisco Planning Department.
6. SAN MATEO	Two census tracts were split between San Mateo County and Santa Clara County DSA's. In one (San Mateo 94), it was determined that the portion assigned to the Santa Clara County DSA was unpopulated so that the tract could be left with San Mateo. The division of the other (San Mateo 65) was determined with the help of the San Mateo County Planning Department, City of San Carlos Planning Department, and the Pacific Gas and Electric Company.
7. SANTA CLARA	Problem as noted above (San Mateo), plus two other split tracts within the county, J 68 and M 91. One was divided by the county planning staff along lines of previous census, and adjustments made from those figures; the second was done by staff using the same method.

---

[a] The final population figures by DSA are given in Table 12.

TABLE 67 (Continued)

8.	SOLANO	Most recent figures are for 1964 (January 1, 1965), and are by city, Vallejo Township, Travis Air Force Base, and "rest of county." DSA populations were calculated by using 1960 census tract data, calculating growth rates for areas by known 1965 figures and projecting as necessary. All figures need to be brought into line with other counties and wastes generation data.
9.	SONOMA	One "planning area" did not coincide with census tract lines and had to be divided, estimation made by staff. Census Tract C was split by DSA line, but this line corresponded to planning area.

APPENDIX G

LAND-USE DATA

TABLE 68

DATA SOURCES AND REFERENCE PERIOD

1. ALAMEDA	July 1, 1966 population estimates prepared by Alameda County Planning Department in conjunction with all cities during October 1966. By county planning areas, planning units (groups of census tracts) and by cities. No indication of method of making estimates. Also population by census tract for Oakland (1965), Berkeley (1965), Fremont (October 1966), Hayward (incorporated portions only, 1965), San Leandro by traffic study zones (1966).
2. CONTRA COSTA	July 1, 1966 population estimates prepared by County Planning Department, by census tracts. Some estimates by County Planning Department based on "known growth patterns;" some estimates by city planning departments, (method unknown). In 1964, county used number of building permits issued plus "growth rate" for estimations.
3. MARIN	January 1, 1966 population estimates published by Marin County Planning Department in "Population Characteristics," by census tracts. All estimates after 1960 by Marin Development Corporation and Marin Chamber of Commerce. Figures also available for January 1, 1965 and January 1, 1967. Methods not indicated.
4. NAPA	January 1, 1966 population estimates by Napa County Planning Department by census tracts. Based on U. S. census of 1960 adding number of residential building permits issued 1960-65 multiplied by number per household figure.
5. SAN FRANCISCO	July 1, 1967 population estimates prepared by San Francisco Health Department, Bureau of Records and Statistics, by census tracts. Figures are prepared annually and kept current by a combination of methods including births, deaths, and housing changes.
6. SAN MATEO	January 1, 1966 population estimates prepared by San Mateo County Planning Department, by census tracts. No indication of method.
7. SANTA CLARA	Population figures by census tracts. Special census as of April 1, 1966. Data tabulated and released by Santa Clara Planning Department, April 1967.
8. SOLANO	January 1, 1965 population estimates prepared by Solano County Planning Department using 1964 estimates(?) plus new dwelling units for 1964, by cities and unincorporated areas. 1964 method of estimation not indicated.
9. SONOMA	January 1, 1967 population estimates by Sonoma County Planning Department, by planning areas, smaller than census tracts. Based on new building permits issued and estimated number per household.

TABLE 69

COMPARISON OF LAND-USE DATA CODE AND WASTES SOURCES[a]

BASS 1965 Data Code		Wastes Source as Defined in This Study	
No.	Description	No.	Description
4	Food	10, 11	Canning and Preserving; Other Food Processing
5	Apparel and Printing	14, 18	Textiles and Apparel; Printing, Publishing, and Allied
6	Miscellaneous Industrial	12, 13, 15-17, 20-23, 30, 31	Ordnance; Wood; Furniture; Paper; Petroleum; Rubber; Leather; Stone; Misc. Manufacturing
7	Chemicals	19	Chemicals
8	Primary Metals	24	Primary Metals
9	Fabricated Metals	25, 26, 28	Fab. Metal Products; Nonelectrical Machinery; Transportation Equipment
10	Electrical Machinery and Instruments	27, 29	Electrical Machinery; Instruments
11	Trucking and Wholesale Trade	6	Commercial and Service Establishments (Private)
12	Transportation, Communication, and Public Utilities	6	Commercial and Service Establishments (Private)
13	Retail Trade	6	Commercial and Service Establishments (Private)
14	Restaurants and Hotels	2	Restaurants and Hotels
15	Finance, Insurance, Real Estate	6	Commercial and Service Establishments (Private)
16	Personal Service	6	Commercial and Service Establishments (Private)
17	Miscellaneous Services	6, 3	Commercial and Service Establishments (Private)
18	Health Services	5	Health Services (Private)
19	Public and Recreational Land	4	Public Facilities and Offices
20	Residential Land	1	Residential
24	Vacant and Agricultural Land	8	Agriculture
25	Total Used and Usable Land		

[a] The BASS land-use data are obtained from the results of the Bay Area Simulation Studies conducted by the Center for Real Estate and Urban Economics, University of California, Berkeley, and published in *Jobs, People, and Land*, 1968. The land-use codes do not exactly correspond to the wastes sources defined in this study. Close comparisons are attempted in this appendix. The data on agricultural land use are aggregated with vacant land and hence are not used in this study. Separate tabulations of agricultural land in detail were made from the County Agricultural Commissioner's Reports. (See text.)

TABLE 70

LAND USE – BASS III: 1965
(acres)

BASS Index Nos. →		4	5	6	7	8	9	10	11	12
Code	Disposal Service Area	Food	Apparel and Printing	Miscel-laneous Industrial	Chemicals	Primary Metals	Fabri-cated Metals	Electrical Machinery and Instruments	Trucking and Wholesale Trade	Transportation, Communication, and Public Utilities
01 01	Berkeley	67	1	102	331	191	69	9	133	107
02	Oakland	893	37	1,220	325	686	723	63	2,616	871
03	Alameda	45	0	139	56	0	138	0	46	63
04	Fremont	52	23	221	192	451	637	4	153	285
05	Pleasanton	1	0	12	0	0	0	0	1	3
06	East Alameda County	23	33	1	0	0	50	0	3	47
02 01	West Contra Costa	106	6	1,046	1,264	58	127	35	313	395
02	Central Contra Costa	79	13	2,032	1,250	512	44	15	409	817
03	East Contra Costa	82	3	895	613	32	54	0	168	126
03 01	West Marin	0	0	0	0	0	0	0	2	4
02	East Marin	19	3	25	0	13	2	4	24	189
04 01	Napa County	196	71	97	3	46	12	2	91	414
05 01	Richmond	3	0	1	0	0	0	0	15	8
02	Marina–Pacific Heights	2	0	4	0	0	1	0	18	75
03	Central	27	8	42	11	22	4	0	78	258
04	South of Market	71	22	87	100	20	162	3	599	270
05	Western Addition	13	0	2	0	0	0	0	26	17
06	Twin Peaks–Buena Vista	6	8	2	0	0	9	0	29	0
07	South Van Ness	62	8	48	7	19	18	0	101	108
08	Potrero–Bayshore	146	5	131	14	65	126	3	387	76
09	Outer Mission	13	1	4	4	6	0	3	103	10
10	So. Frwy–Mt. Davidson	1	2	1	1	1	4	1	46	24
11	Lake Merced	0	0	0	0	0	0	0	468	5
12	Sunset	0	0	7	0	0	0	0	52	11
06 01	Daly City	0	0	5	0	0	1	0	6	47
02	South San Francisco	164	9	174	309	398	113	18	685	160
03	Pacifica	0	0	0	0	0	0	0	6	7
04	Central San Mateo	127	67	233	252	211	153	220	682	594
07 01	Palo Alto	27	7	155	14	8	56	214	94	83
02	Mountain View	8	2	120	14	3	74	151	55	121
03	Sunnyvale	64	4	8,983	19	3	37	45	236	129
04	Gilroy–Morgan Hill	264	1	59	81	0	54	0	138	63
05	Los Gatos	1,330	22	72	2	1	112	27	169	75
06	Los Altos	200	15	571	52	296	78	26	254	97
07	San Jose	716	19	853	180	170	1,002	74	1,017	824
08	Remainder of County	648	400	400	400	400	400	400	400	0
08 01	Vacaville	159	3	5	0	0	0	0	17	43
02	Fairfield	123	1	11	0	0	34	0	3	164
09 01	Healdsburg	28	1	258	12	2	1	0	33	75
02	Santa Rosa	54	2	69	2	6	14	6	126	353
03	Western Sonoma	4	4	4	4	4	4	4	4	0
04	South Sonoma	4,708	411	4,790	0	11	2,046	0	3,719	50
NINE-COUNTY TOTAL		10,531	1,212	22,881	5,512	3,635	6,359	1,324	13,525	7,068

TABLE 70 (continued)

	13	14	15	16	17	18	19	20	24	
DGA	Retail Trade	Restaurants and Hotels	Finance, Insurance, and Real Estate	Personal Services	Miscel- laneous Services	Health Services	Public and Recreational Land	Residential Land	Vacant and Agricultural Land	Total of Columns 4-24
01 01	125	36	53	26	106	42	1,281	5,326	677	8,682
02	953	132	252	136	574	231	8,491	36,138	39,051	93,392
03	35	6	9	6	27	17	2,0	2,594	854	6,107
04	115	16	41	24	83	10	1,737	10,346	39,676	54,066
05	9	1	2	1	7	1	0	381	71,162	71,581
06	25	2	7	2	7	9	283	3,440	93,668	97,600
02 01	392	56	62	52	212	56	7,321	14,559	19,906	45,966
02	540	98	106	37	289	116	17,080	40,182	168,439	232,058
03	117	32	20	11	76	17	981	4,600	108,115	115,942
03 01	0	1	0	0	7	1	63,078	1,540	96,887	161,520
02	78	15	25	12	50	24	8,829	6,516	53,893	69,721
04 01	135	24	28	14	59	40	90,067	6,011	225,166	322,476
05 01	46	11	35	8	40	55	1,590	1,922	66	3,800
02	23	8	13	8	28	24	1,658	931	42	2,835
03	41	61	85	8	49	16	206	538	102	1,556
04	11	3	3	8	23	0	130	199	141	1,852
05	24	6	11	11	50	17	159	419	48	803
06	11	2	8	8	25	9	464	1,093	156	1,830
07	25	4	24	2	8	4	137	328	76	979
08	6	0	2	0	4	0	1,045	797	653	3,460
09	49	9	18	10	59	25	836	1,855	216	3,218
10	16	2	16	4	24	1	512	1,572	309	2,537
11	56	2	11	3	21	4	1,157	998	94	2,819
12	37	5	24	9	43	6	382	2,804	112	3,492
06 01	95	11	39	10	29	8	1,827	2,879	1,449	6,406
02	69	18	11	5	43	7	3,496	6,810	4,296	16,785
03	35	4	9	2	23	3	1,129	3,242	3,426	7,886
04	404	85	133	63	770	74	12,319	26,013	123,313	165,213
07 01	75	17	32	12	66	36	1,976	4,469	3,099	10,440
02	120	8	12	7	49	9	366	2,436	2,091	5,646
03	77	38	18	7	49	9	1,797	4,400	9,681	25,596
04	55	11	13	3	18	21	579	3,351	51,755	56,466
05	228	39	38	25	99	65	2,538	13,979	36,052	54,873
06	162	43	46	21	147	59	2,422	20,138	29,578	54,205
07	418	57	116	34	182	60	4,347	19,356	63,532	92,957
08	0	0	17	0	63	0	17,410	1,898	136,180	159,016
08 01	14	13	3	1	8	0	7,526	1,050	181,697	190,539
02	20	4	5	0	14	3	27,726	2,207	244,557	274,872
09 01	48	13	18	10	28	20	6,662	810	176,002	184,021
02	108	20	95	10	41	37	7,337	1,017	103,785	113,082
03	0	0	0	0	37	0	8,782	634	149,223	158,788
04	31	7	6	5	18	8	15,808	962	185,544	218,124
TOTAL	4,828	920	1,466	615	3,055	1,144	333,543	260,760	2,424,769	3,103,147

APPENDIX H

DETERMINATION OF CELLULOSE IN SEWAGE

DETERMINATION OF CELLULOSE IN SEWAGE
(RAW AND DIGESTED SLUDGES)

The method described herein is basically a modification of a standard procedure recommended by the Technical Association of the Pulp and Paper Industry. In the absence of the interferences imposed by sewage, the cellulose content of wood pulp and paper is quite easily determined by an extraction with sodium chlorite and glacial acetic acid at an elevated temperature. In this procedure, the noncellulosic constituents of the paper and pulp are hydrolized, leaving a residue of cellulose which may be measured gravimetrically.

The presence of sewage or sewage sludges complicates the method, in that interfering substances are introduced which are not hydrolyzed. Of particular importance in this respect are proteins and inorganics. Proteins are removed in a preextraction step in which hydrolysis is accomplished by refluxing with a strong base. It is then necessary to remove the base, which is done by washing, centrifugation, and decanting. Inorganics are measured by igniting the extracted samples and determining the weight differences. The fixed solids then represent the inorganics, and the volatilized material is the cellulose content.

Outline of the Procedure

Apparatus

1. Filtering crucibles. Gooch type with fritted disc, Pyrex brand glass, 30-mℓ capacity, porosity C (or porosity μ).
2. Reflux apparatus.
   - a. Erlenmeyer flasks, 300-mℓ capacity.
   - b. Reflux condensers, water-packeted.
3. Centrifuge tubes – thick wall, 250-mℓ capacity.
4. Water bath, 70°C.

Cellulose Determination

1. Dilute a 25-mℓ sludge sample to 100 mℓ in a 250-mℓ flask.
2. Add 0.60 mℓ of 50% NaOH and 2.5 mℓ antifoam.
3. Reflux for 30 minutes using water condensers to avoid loss of solution.
4. Cool, transfer to 250-mℓ centrifuge bottles, add H_2O to approximately 230 mℓ, centrifuge for 20 minutes at 1800 rpm.
5. Decant. Repeat H_2O wash, mixing solids, and centrifuge again.
6. Decant. Add H_2O to 50 mℓ mark on centrifuge flask.
7. Bring to 70°C in water bath.

8. Add 1.25 g of sodium chlorite and swirl to mix.[a]
9. Add 0.50 mℓ glacial acetic acid and mix again.[b]
10. Hold in 70°C water bath for 5 minutes.[c]
11. Transfer to 30-mℓ fritted glass, porosity C, Buchner-type funnel (previously ignited and tared).
12. Remove liquid by suction.
13. Wash residue with distilled H_2O until chloride-free. (Test with one drop of $AgNO_3$ and one drop of 1% HNO_2.)
14. Wash residue with 25 mℓ of 80% ethanol.
15. Dry in oven at 105°C for 2 hours, cool in desiccator, and weigh.
16. Ignite at 500°C for 1 hour, cool, and weigh.
17. Difference after ignition is weight of cellulose.

Testing the Method

The accuracy and precision of the method were determined in a series of recovery tests in which cellulose was added in two forms: powdered and as paper pulp. Digested and raw sludges were used as the suspending media.

1. Recovery of Callulose Added to Digested Sludge

Cellulose Source – Genuine Whatman Cellulose Powder, Coarse Grade (Ashless)

A. Background – Cellulose Content of Digested Sludge

Replicate	Cellulose, mg/25 mℓ
1	47.57
2	51.00
3	50.98
4	49.14
5	50.25
Avg.	49.88

$\sigma = 1.45$ mg

$C_v = 2.91\%$

B. **Recovery – Added Cellulose** (1.02136 g blended with 300-mℓ portion of above batch of digested sludge – 25 mℓ aliquots withdrawn)

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[a] For samples containing wood add 2.5 g sodium chlorite.

[b] For samples containing wood add 1.0 mℓ glacial acetic acid.

[c] For samples containing wood hold in water bath until cellulose is whitish in appearance – stir occasionally.

Replicate	Input Cellulose, mg			Recovered Cellulose, mg
	Background	Added	Total	
1	49.88	85.11	134.99	127.17
2	49.88	85.11	134.99	130.46
3	49.88	85.11	134.99	139.38
4	49.88	85.11	134.99	131.42
Avg.	49.88	85.11	134.99	132.11

Note: Used coarse porosity filters

Analysis: Avg. (of added) recovered $\frac{132.11 - 49.88}{85.11} \times 100 = \underline{96.5\%}$

Conclusions: 1. The procedure effects a 96.5% recovery of the added cellulose powder in digested sludge samples.

2. The standard deviation (of added) cellulose recovered σ is 5.95 mg and the coefficient of variance, C_V, is 7.0% indicating quite satisfactory precision and accuracy.

3. The replicates to determine the background cellulose content showed good precision, the σ being 1.45 mg, and the C_V, 2.91%.

2. Recovery of Cellulose Added to Raw Sewage Sludge

A. Cellulose Source — Whatman Powder

Test 1

(1) Background — Cellulose content of raw sewage sludge (half-strength)

Replicates	Cellulose, mg/12.5 ml
1	359.37
2	343.21
3	367.04
4	361.58
Avg.	357.80

σ = 10.24 mg

C_V = 2.87%

(2) Recovery — Added cellulose powder to portion of above batch of sludge

Replicate	Input Cellulose, mg			Recovered Cellulose, mg
	Background	Added	Total	
1	357.80	997.70	1355.50	1202.30
2	357.80	998.17	1355.97	1233.80
3	357.80	997.65	1355.45	1196.88
4	357.80	997.22	1355.02	1179.45
Avg.	357.80	997.69	1355.49	1203.11

Note: Used medium porosity filters

Analysis: % (of added) recovered $\frac{1203.11 - 357.80}{997.69} \times 100 = \underline{84.8}\%$

σ (of added) recovered = 22.67 mg

C_v (of added) recovered = 2.28%

Test 2

(1) Background — Cellulose content of half-strength raw sewage sludge

Replicates	Cellulose, mg/12.5 mℓ
1	466.90
2	448.65
Avg.	457.78

(2) Recovery — Added cellulose powder to portion of above batch of sludge

Replicate	Input Cellulose, mg			Recovered Cellulose, mg
	Background	Added	Total	
1	457.78	511.03	968.81	909.58
2	457.78	509.47	967.25	894.20
Avg.	457.78	510.25	968.03	901.89

% (of added) recovered $\frac{901.89 - 457.78}{510.25} \times 100 = \underline{87.31}\%$

B. Cellulose Source — Paper Pulp

Test 1

(1) Background — Cellulose content of raw sewage sludge

Replicates	Cellulose, mg/25 mℓ
1	470.55
2	459.05
3	454.20
4	432.28
Avg.	454.02

σ = 16.03 mg

C_v = 3.53%

(2) Recovery — Added cellulose (paper pulp) to portion of above batch of raw sludge

Replicate	Input Cellulose, mg			Recovered Cellulose, mg
	Background	Added	Total	
1	454.02	1265.10	1719.12	1488.75
2	454.02	469.78	923.80	997.00
3	454.02	608.69	1062.71	1012.00
4	454.02	599.07	1053.09	1215.08
Avg.	454.02	735.66	1189.68	1178.21

Note: Used coarse porosity filters

Analysis: % (of added) recovered $\frac{1178.21 - 454.02}{735.66} \times 100 = \underline{98.2}\%$

Test 2

(1) Background — Cellulose content of half-strength raw sewage sludge

Replicates	Cellulose, mg/12.5 mℓ
1	240.60
2	242.94
3	249.86
4	244.61
Avg.	244.50

σ = 3.93 mg

C_v = 1.61%

(2) Recovery — Added cellulose (as paper pulp) to portion of above batch of raw sludge

Replicate	Input Cellulose, mg			Recovered Cellulose, mg
	Background	Added	Total	
1	244.50	496.27	740.77	759.02
2	244.50	496.94	741.44	725.32
3	244.50	493.91	738.41	715.76
4	244.50	498.01	742.51	729.91
Avg.	244.50	496.28	740.78	732.50

Note: Used coarse porosity filters

Analysis: % (of added) recovered $\frac{732.50 - 244.50}{496.28} \times 100 = \underline{98.3\%}$

$\sigma = 17.72$ mg

$C_V = 3.63\%$

3. Causes of Loss of Cellulose Powder in the Procedure

A. Loss by filtration: Loss by filtration was investigated by using only the filtration step of the procedure, i.e., filtered a powder-distilled water mixture through glass filters and noted recovery.

(1) Course Porosity Filters

Replicate	Cellulose Added, mg	Cellulose Recovered, mg	Recovered %
1	504.06	485.86	96.39
2	999.60	963.77	96.42
3	2003.90	1930.42	96.33
Avg.	1169.19	1126.68	96.38

(2) Medium Porosity Filters

Replicate	Cellulose Added, mg	Cellulose Recovered, mg	Recovered %
1	99.94	95.71	95.77
2	99.74	95.60	95.85
3	99.74	96.62	96.87
4	99.74	105.49	105.76
5	99.78	96.66	96.87
Avg.	99.79	98.02	98.20

B. Loss by Centrifugation: Loss of centrifugation was investigated by applying full procedure to a cellulose powder–distilled water mixture.

1800 rpm Centrifugation

Replicate	Cellulose Added, mg	Cellulose Recovered, mg	Recovered %
1	99.56	85.09	85.47
2	99.55	90.08	90.49
3	99.83	94.28	94.44
4	99.89	94.00	94.10
Avg.	99.708	90.862	88.75

$\sigma = 11.1$ mg

$C_V = 11.14\%$

Discussion:

In tests in which cellulose was added as a powder to digested sludge, 96.5 percent of the material was recovered. The coefficient of variance (C_V) was 7.0 percent. When cellulose powder was added to raw sludge, recovery was within the range of 85 to 88 percent. Adding the cellulose in the form of particles of paper pulp resulted in significantly higher recoveries. Thus, 98 percent of the cellulose added as paper pulp to raw sludge was recovered. The C_V in this case was 3.63 percent.

Inasmuch as the greater part of the cellulose to be found in sewages would be in a form comparable to that of the pulp used in the recovery tests, the 98 percent recovery of cellulose added as small pieces of paper pulp in the present tests can be considered to be generally representative of the method's accuracy and precision when applied to the determination of cellulose in sewage and sewage sludge.

The high degree of precision of the technique also was shown in the determinations of the background cellulose content in raw and in digested sludge media. In tests involving raw sludge, the coefficients of variation in three series of tests were respectively: 2.87 percent, 1.61 percent, and 3.53 percent. The C_v in replicate analyses of the cellulose content of digested sludge medium was 2.91 percent.

The loss of cellulose when added as a powder was found to take place in two of the procedural steps; namely, filtration and centrifugation. Loss by way of the filtration step was investigated by filtering a suspension of powdered cellulose in distilled water through a filter of coarse porosity, and also through one of medium porosity. (These porosities would be the only practical ones for tests involving sewage or sewage sludge.) The loss of fines through the coarse filter amounted to 3.62 percent; and that through the fine filter, 1.80 percent. Paper pulp did not pass through either type of filter paper. In the investigation of loss by way of the centrifugation step, it was found that cellulose powder was lost in centrifugation only when it was suspended in a raw sludge medium. The loss amounted to about 10 percent. No loss occurred when the powder had been suspended in digested sludge. Apparently, the cellulose fines were occluded by the smaller particles present in the digested sludge.

Summary and Conclusions

1. Cellulose powder is not as readily recoverable (84.8%) in raw sludge samples as it is in digested sludge (96.5%).
2. Cellulose in the form of paper pulp is almost completely recovered from raw sludge (98.3%), with very good accuracy (C_v = 3.63%).
3. For the most part, the cellulose present in sewage sludge would be expected to be in the form of small particles of paper pulp rather than in the finely divided state of cellulose powder, thus the results of the paper pulp recovery test are probably an accurate representation of the recovery effected by the procedure when raw sewage sludge is used.
4. Loss of fines through course filters was 3.62% and through medium filters was 1.80%.
5. Standard deviation, σ, = 4.65 mg in medium filters and the coefficient of variance, C_v, = 4.66%.
6. The major source of loss of finely divided cellulose powder is the centrifugation step.
7. A loss of 11.25% was noted.
8. This loss is found in both water and raw sludge analyses, but not in digested sludge analyses. Apparently the powder is blanketed by digested sludge particles during centrifugation and the fines are precipitated by occlusion.

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